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NOISE AND VIBRATION IN MINES
RESEARCH REPORTS 1972-1986

edited by G. Knight ***traduit par N.R Billette***

Volume 5 MRL 88–120 (R)

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Canada Centre for Mineral and Energy Technology

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NOISE AND VIBRATION IN MINES RESEARCH REPORTS: 1972-1986. VOLUME 5—NOISE ABATEMENT STUDIES

BRUIT ET VIBRATION DANS MINES RAPPORTS DE RECHERCHE ÉTUDES DE RÉDUCTION DU BRUIT

Edited by G. KNIGHT
Canadian Mine Technology Laboratory

Traduit par N.R. Billette
Laboratoire canadien de technologie minière

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RAPPORT DE DIVISION LRM 88–120 (R)

FOREWORD

The compendium of CANMET reports on noise measurement equipment, noise assessments in mines and hearing protection assessments is a tribute to the dedication, hard work and professional expertise of Mr Savich in his field of research specialization. The research contained within the reports was accomplished by Mr. Savich or under his direction in the relatively brief period of 1972 to 1986 while working as a research scientist at the Elliot Lake Laboratory.

It is hoped that this compendium of reports on research carried out while at CANMET will be useful to those interested in finding solutions to the problems caused by miner exposure to noise and vibration.

J.E. Udd
Director
Mining Research Laboratories

AVANT-PROPOS

Le recueil de rapports de CANMET sur les instruments de mesure du bruit, les évaluations du bruit dans les mines et la protection de l'ouïe constitue un hommage à l'assiduité, le professionnalisme et l'expertise de M. Savich dans son champ de spécialisation en recherche. La recherche relatée dans ces divers rapports fût accomplie par M. Savich lui-même, ou sous sa direction, au cours de la courte période allant de 1972 à 1986, alors qu'il oeuvrait en tant que chercheur scientifique au laboratoire d'Elliot Lake.

Les Laboratoires de recherche minière de CANMET espèrent que ce recueil de rapports de recherche serviront à tous les intervenants du milieu intéressés aux problèmes reliés à l'exposition des mineurs au bruit et aux vibrations.

Directeur
Laboratoires de recherche minière
J.E. Udd

NOISE AND VIBRATION IN MINES — RESEARCH REPORTS: CANMET/ MINING RESEARCH LABORATORIES, 1972-1986.

Reprinted in 6 Volumes

Edited by

G. Knight*

French translations by

N.R. Billette*

ABSTRACT

This compendium is a reprint of all the reports on noise and vibration research undertaken by CANMET. Most of the studies were undertaken in cooperation with mines across Canada, mainly mines located in Ontario and on several occasions with the Mines Accident Prevention Association of Ontario. Two studies were carried out through the awarding of contracts.

The compendium is in 6 volumes, two of which are in parts, as follows;

1. Vol. 1–Glossary, Introduction, and Measurement Methods.
2. Vol. 2–Hearing Protection—Ear Muffs.
3. Vol. 3–Mine Noise Surveys–Part A.
4. Vol. 3–Mine Noise Surveys–Part B.
5. Vol. 3–Mine Noise Surveys–Part C.
6. Vol. 4–Mill and Surface Plant Noise Surveys–Part A.
7. Vol. 4–Mill and Surface Plant Noise Surveys–Part B.
8. Vol. 5–Noise Abatement Studies.
9. Vol. 6–Vibration Studies and General(includes unclassified)

Within each volume or section the reports are listed chronologically. The glossary has been removed from 3 of the reports and listed separately at the front. The introduction describes the main features of the contained studies in each volume.

KEYWORDS: Noise, vibration, mine surveys, noise control,
hearing protection, bibliography.

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BRUIT ET VIBRATION DANS LES MINES - RAPPORTS DE RECHERCHE: LABORATOIRES DE RECHERCHE MINIÈRE DU CANMET, 1972-1986.

Réimpression (en anglais) dans 6 Volumes

édité par G. Knight*

traduit par N.R. Billette*

RÉSUMÉ

Ce recueil constitue une réimpression de tous les rapports concernant la recherche sur le bruit et les vibrations exécutée à CANMET. La plupart des travaux ont été entrepris en collaboration avec des mines canadiennes, principalement avec des mines situées en Ontario et, en de nombreuses occasions, avec l'assistance de l'Association de prévention des accidents miniers en Ontario (MAPAO). Deux recherches furent réalisées en tant que contrats.

Le recueil comprend 6 volumes, dont deux comprenant plus d'une partie, répartis comme ceci:

1. Vol. 1–Glossaire, introduction et techniques de mesure.
2. Vol. 2–Protection de l'ouïe - protecteurs supra-auriculaires.
3. Vol. 3–Relevés de bruits de mines–partie A.
4. Vol. 3–Relevés de bruits de mines–partie B.
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6. Vol. 4–Relevés de bruits d'usines et d'ateliers de surface–partie A.
7. Vol. 4–Relevés de bruits d'usines et d'ateliers de surface–partie B.
8. Vol. 5–Études de réduction du bruit.
9. Vol. 6–Études des vibrations et divers.

Dans chaque volume ou section, les rapports sont classés en ordre chronologique. Le glossaire (en anglais seulement) provient de l'amalgamation de termes contenus dans trois des rapports et a été regroupé séparément au début. L'introduction décrit les principaux éléments des travaux contenus dans chaque volume.

MOTS-CLÉS: bruit, vibration, relevé en mine, contrôle du bruit, protection auriculaire, bibliographie.

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INTRODUCTION

This research was undertaken because noise-induced hearing loss is a substantial problem in the mining industry and because vibration-induced damage occurs to blood capillaries in the hands of miners, particularly drillers. Noise-induced hearing loss generally occurs over a long period of time. Because humans are adaptable and tend to compensate for the gradual loss, the impairment goes unrecognized for a long time. Exposure to very loud noises, such as explosions, can give rise to immediate and disabling damage to the hearing system.

Hearing impairment affects both employees and employers. Compensation payments are becoming substantial. The hearing loss can only be detected in the early stages by frequent checks of hearing acuity and this is now required for miners in most Canadian jurisdictions.

Noise is measured as the peak to trough pressure difference in the vibration waves in air. The results are expressed in relative terms to the hearing sensitivity of (young adult) humans in good health using a logarithmic scale to the base 10. Thus, an increase of one Bel is equivalent to a ten times stronger noise level. However, the Bel is a large unit and it is more convenient to use a unit ten times smaller, the decibel. Hearing acuity is frequency dependent. It peaks at a frequency of about 1 000 Hertz (cycles per second) and falls off to the extreme limits, roughly 20 and 20 000 Hz. Sound measurement equipment is much less frequency dependent and a weighting factor is used to relate it to human hearing. The "A"-scale is used in hearing loss programs generally. Thus, the weighted noise level in decibels is usually abbreviated as dBA. Hearing loss is believed to occur when exposure is above a threshold level, 85 dBA and 90 dBA have been specified in various jurisdictions. The hearing loss is proportional to the height of the noise excursion and its duration. Three factors are in use for equating the potential hearing loss to the noise level:

1. A doubling every 3 dBA–The equal energy principle, used in many hearing loss control recommendations.
2. A doubling every 4 dBA–used in one or more recommendations.
3. A doubling every 5 dBA–used in the principal USA legislation: the Occupational Safety and Health Act (OSHA).

Canadian regulations are set provincially and federally: either factor 1 or 3 is used.

In addition to potential hearing losses high noise levels lead to problems in safety, fatigue and communication.

Most of the noise studies have been directed at surveys of noise in mines and the efficacy of hearing protection measures. The mine surveys have shown that many miners are exposed to noise levels above the threshhold for potential hearing loss and that immediate hearing protection is required as well as an effort to reduce the noise level of mining machinery.

This compendium is a reprint of all the reports on noise and vibration research undertaken by CANMET. Most of the studies were undertaken in cooperation with mines across Canada, mainly mines located in Ontario and, on several occasions, with the Mines Accident Prevention Association of Ontario. Two studies were carried out through the awarding of contracts. A few of the early reports by Miron Savich were based on his MSc. thesis work undertaken at the Institute of Mineral Research of McGill University, situated at Mont St. Hilaire, Quebec.

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Within each volume or section the reports are listed chronologically. The glossary has been removed from 3 of the reports and amalgamated. It is presented separately at the front, following the contents table.

The noise measurement methods used are described in some reports in the first volume as well as being described in many of the other reports on surveys etc.. Five main classes of noise measurement techniques have been used in the noise surveys. These are:

1. Hand-held meters with "A"-scale weighting and slow response time averaging over a short period of time, a second or less, with manual recording. This was used in the earlier surveys and occasionally later. A graphical method of determining the average noise level for the survey is given in report 75–71.
2. The hand-held sound level meter was also used in the peak measurement mode for studies of impulse, or short duration, noise as in report 84–83.

3. A shift length recording system in which the average noise level over a period, such as a minute, is stored on a memory bank and read out later. In the system used, the results were read at the end of the shift and analysed using a computer program as described in report 78–62.
4. The noise dosimeter averages noise level over a short period of time and, if it exceeds the threshhold, adds it up using an appropriate factor to give the noise level as a ratio of the exceedance to permissible for the shift. The instrument usually has an indicator for showing whether the noise level has exceeded the ceiling level of 115dBA promulgated in the OSHA regulations (presumably intended for unprotected ears). This instrument has been used in many surveys and tests on hearing protectors. One unit was described and tested in report 76–83.
5. Frequency analysis sound level meter. This determines the sound level in each band of frequency of significance, usually one third octave wide. The equipment is desirable because the attenuation of noise by any barrier is frequency dependent and because the frequency of an offensive sound may be very helpful in determining its source. Ear muffs are sound attenuators and therefore frequency dependent, they are not as good attenuators at low frequencies as at high frequencies.

Ear muffs (hearing protectors) were shown to be highly efficient in laboratory tests providing attenuations of 31 to 44 dBA at frequencies of 1 000 Hz and above. Safety glass-frames passing under the seal of the ear muff, however, were found to reduce attenuations to 25 to 34 dBA. The wearing of safety glasses is obligatory in most working places in the mining industry. Field studies in mines showed that the effective protection factors for ear muffs could be less than 10 dBA. The surveys carried out at Falconbridge Mines Ltd., Reports 86–58, 86–59, 86–60, 86–61 with a final summary in 86–88 illustrate the value of such studies. The attenuations of ear muffs found in mines are shown in Figure 1, where the measured attenuation(OSHA basis) in dBA is shown plotted against the mean sound level in dBA (variously described in the reports as $L_{eq}(60s)$; L_{OSHA} or $L_{Avg.}$). The required attenuation line is drawn assuming that the average sound levels persist for a full 8 hour shift and that ear plugs are not worn. This figure suggests that about half of the population examined were not protected to the extent required. However, neither of these assumptions are true and it is probable that substantially more than the half of the population was protected to the extent required. The major reason for the poor performance of ear muffs in practise was found to be poor fitting, the spring clamping force was often inadequate, particularly on small headed individuals. Emphasis was placed on the measurement and control of clamping force and the need to fit earmuff supports to head size. On the basis of these surveys recommendations were made to improve control of hearing protection programs.

The noise surveys are a useful repository of information. The detailed surveys, using the data logging technique, which form the major part of volumes 3 and 4, provide invaluable information to those planning noise control programs in many mining operations. Nearly 700 man-days were logged in the detailed surveys. It could be seen that the distribution of noise exposure during the shift varies from nearly constant to highly variable. In the mines 262 shifts out of the 432 recorded were worked at sound levels above permissible exposure. The highest values were about 40 times greater requiring hearing protection of at least 28 dBA attenuation. This would be even higher if the proposed OSHA standards instead of the existing rules (at the time the reports were written) were used as the basis for assessment. In the mills and surface plants only 13 out of the 250 shifts recorded were worked at sound levels above permissible exposure. The highest value required about 10 dBA attenuation in the hearing protection.

Noise control studies have been carried out with respect to light and medium weight percussion rockdrills, diamond drills and diesel engine exhaust systems. The diamond drill studies point out the need for a thorough investigation of all the noise sources, four major sources have been identified. Reduction of only one source would, as a result, produce almost no effect on sound level, a reduction of about 1 dBA. It may, however, modify the sound quality significantly.

The high noise levels measured in mining emphasize the requirement for substantial work to control noise on mining machinery. It is likely that eventually it will be desirable not to expose men to sound levels over 85 dBA and that the necessity for hearing protection will be considered an undesirable working condition to be eliminated.

The contract study on vibration found that stopers and jackleg drills subjected miner's hands to vibration levels sufficient to induce vibration white finger disease in periods of one to four years in over half the population. It was also shown that vibration isolators could be effective in substantially reducing vibration transmission to hands and proposed that vibration isolation handles should be developed and used on percussion drills. Some sites where whole-body exposure to vibration exceeded guidelines were found in surface plant and mills. Underground diesel powered vehicles were not examined.

The report 73-17 in the miscellaneous section in volume 6 is a good exposition of the noise and vibration problems in mines. The topics covered include noise and vibration measurement; noise and vibration exposure standards; and noise and vibration sources; as well as control methods.

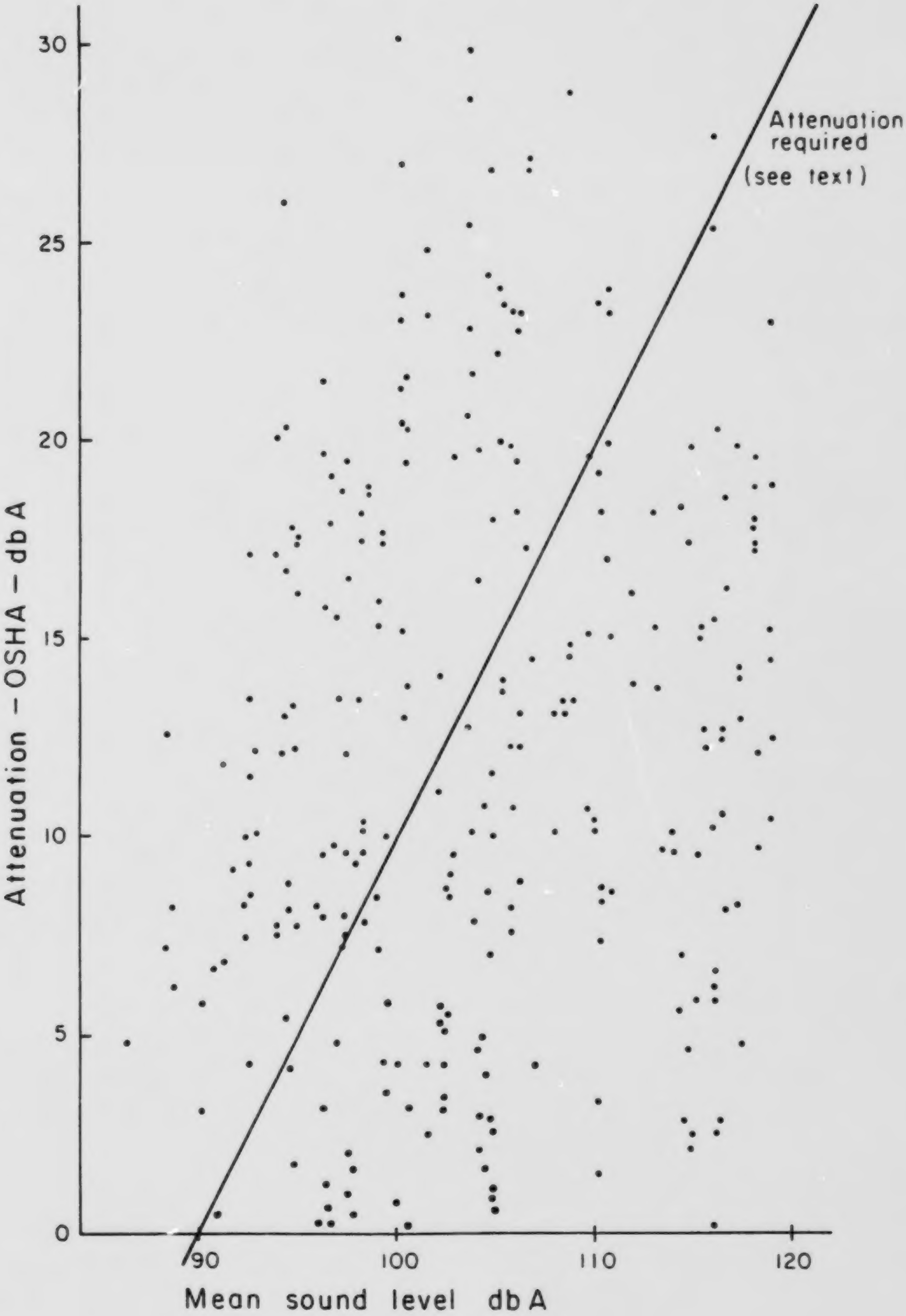

Fig. 1–The attenuation of ear muffs measured in use in mines.

Fig. 1–L'atténuation des protecteurs supra-auriculaires en usage dans le mines

It should be appreciated that many of the reports cover more than one topic and that they have not been cross-referenced. They are entered in the category corresponding to the major aspect studied.

The report pages have not been renumbered. To assist in locating each report red coloured pages are used to separate them. Each of these has page and report numbers in the top right hand corner and the full title and description of the report and its publication details, if other than a divisional report.

The reports are in their original language, usually english. The abstracts have been translated into french and are given at the front of each report.

ACKNOWLEDGEMENTS

The editor wishes to thank his colleagues in the Mining Research Laboratories for assistance in gathering and compiling these reports.

INTRODUCTION

Ces travaux de recherche ont été entrepris parce que la perte auditive due au bruit constitue un problème important dans l'industrie minière, ainsi qu'à cause des dommages aux capillaires sanguins induits par vibration aux mains des mineurs, et plus particulièrement des foreurs. La perte auditive due au bruit découle d'une exposition prolongée. Puisque les humains s'adaptent facilement et tendent à compenser la perte graduelle, la détérioration passe longtemps inaperçue. Toutefois, l'exposition à de très grands bruits, une explosion par exemple, peut entraîner un dommage immédiat incapacitant du système auditif.

La perte auditive affecte tant l'employeur que l'employé. Les paiements compensateurs sont devenus substantiels. Les premiers signes de dégradation de l'ouïe ne sont reconnus qu'au prix de multiples vérifications de l'acuité auditive, ce qui est maintenant exigé dans la plupart des juridictions canadiennes concernant les mineurs.

Le bruit est mesuré comme différence entre le sommet et le creux des ondes vibratoires dans l'air. Les résultats sont exprimés en termes relatifs à la sensitivité auditive d'un humain (jeune adulte) en bonne santé, en utilisant une échelle logarithme de base 10. Ainsi, une augmentation du niveau sonore d'un Bel équivaut à décupler l'énergie acoustique. Toutefois, le Bel constitue une unité représentant une somme énergétique importante, de sorte qu'il est plus approprié d'utiliser le décibel, une unité dix fois plus petite. L'acuité auditive dépend de la fréquence de l'onde. Elle atteint son maximum aux alentours de la fréquence de 1,000 Hertz (cycles par seconde) et diminue aux deux extrémités du spectre, soit 20 et 20,000 Hz respectivement. L'équipement de mesure du son est beaucoup moins dépendant de la fréquence utilisée, de sorte qu'un facteur de pondération est nécessaire pour relier le niveau sonore à l'acuité auditive humaine. L'échelle "A" est généralement utilisée dans les programmes de perte auditive. Dans ce cas, le niveau sonore pondéré est habituellement abrégé à dBA. La perte auditive est considérée se produire au-delà d'un seuil, 85 dBA et 90 dBA étant la norme dans diverses réglementations. La perte auditive est proportionnelle à la puissance de l'onde sonore et à la durée de l'exposition. Trois facteurs légaux sont utilisés pour établir la relation entre dommage potentiel et niveau sonore:

1. Le dommage double tous les 3 dBA – le principe d'énergie équivalente, à la base de nombreuses recommendations du contrôle de la perte auditive.
2. Le dommage double tous les 4 dBA – utilisé dans une recommendation ou plus.
3. Le dommage double tous les 5 dBA – en usage dans la principàles législation américaine, l'Acte de santé et sécurité occupationnelles (OSHA).

Les réglementations canadiennes sont émises aux niveaux provinciaux et fédéral: elles utilisent le facteur 1 ou le facteur 3.

En plus des pertes auditives potentielles, les niveaux sonores élevés entraînent des problèmes de sécurité, de fatigue et de communications.

La plupart des travaux sur le bruit ont été orientés vers des relevés du bruit dans les mines et vers l'appréciation de l'efficacité des mesures de protection de l'ouïe. Les relevés dans les mines ont démontré que plusieurs mineurs sont exposés à des niveaux sonores supérieurs au seuil de dommage auditif potentiel et qu'une protection immédiate de l'ouïe est nécessaire en parallèle à l'implantation de mesures de réduction du bruit de l'équipement et matériel minier.

Ce recueil incorpore tous les rapports de recherche sur le bruit et les vibrations réalisés par CANMET. La plupart des travaux ont été réalisés en collaboration avec des mines canadiennes, principalement avec des mines situées en Ontario et, à maintes reprises, avec l'assistance de l'Association de prévention des accidents miniers en Ontario (MAPAO). Deux recherches furent réalisées sur une base contractuelle. Quelques uns des premiers rapports de Miron Savich étaient basés sur sa thèse de maîtrise réalisée à l'Institut de Recherche minérale de l'Université McGill, situé à St-Hilaire, Québec.

Le recueil comprend six volumes, dont deux en plusieurs parties, comme suit:

1. Vol. 1–Glossaire, introduction et techniques de mesure.
2. Vol. 2–Protection de l'ouïe - protecteurs supra-auriculaires.
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Dans chaque volume ou section, les rapports sont classés en ordre chronologique. Le glossaire (en anglais seulement) provient de l'amalgamation de termes contenus dans trois des rapports. Il est présentement à part au début, tout de suite après la table des matières.

Les techniques de mesure du bruit utilisées sont décrites dans quelques rapports du premier volume, ainsi que dans de nombreux autres reliés aux relevés de mines, usines et ateliers. Cinq classes principales de techniques de mesure du bruit ont été expériementées dans les relevés sonores. Ce sont:

1. Des appareils manuels pondérant les fréquences selon l'échelle "A", avec un temps de réponse assez lent et le calcul de la valeur moyenne sur une brève période, une seconde ou moins, et enregistrement manuel du résultat. Il s'agit de la technique utilisée lors des premiers relevés, puis occasionnellement par la suite. Une méthode graphique pour déterminer le niveau acoustique pondéré au cours du relevé est expliquée dans le rapporté 75-71.
2. Le sonomètre manuel a aussi été utilisé en mode de mesure des bruits d'impact pour des études d'impulsion, ou bruit de courte durée, comme dans le rapport 84-83.
3. Un système d'enregistrement pour la période de travail (8 heures), qui cumule le bruit moyen d'une période de courte durée, une minute par exemple, et la conserve en mémoire pour lecture ultérieure. Le système utilisé permettait la lecture de l'information à la fin de la période de travail et son traitement ultérieur informatisé, tel que décrit dans le rapport 78-62.
4. L'audio-dosimètre calcule le niveau sonore moyen sur une courte période de temps et, surtout s'il excède le niveau légal, calcule le rapport du niveau sonore obtenu au niveau permis pour la période de travail. L'instrument possède également un voyant lumineux qui indique un dépassement de la limite légale absolue de 115 dBA promulguée dans les règlements OSHA (sans aucun doute pour une ouïe sans protecteur). Cet instrument a été utilisé dans plusieurs relevés et lors de tests concernant les protecteurs auriculaires. Un tel appareil a été décrit et vérifié dans le rapport 76-83.
5. Le sonomètre d'analyse fréquentielle. Cet instrument mesure le niveau acoustique moyen dans chaque bande de fréquence significative, habituellement de la largeur d'un tiers d'octave. L'instrument est nettement recommandable, puisque l'atténuation du bruit par toute barrière est fonction de la fréquence et parce que la fréquence d'un son agresseur contribue à localiser sa source. Les protecteurs auriculaires sont des atténuateurs de son et, de ce fait, dépendent de la fréquence d'émission. Ils n'atténuent pas les basses fréquences avec autant de bonheur que les hautes fréquences.

Les protecteurs supra-auriculaires ont démontré des habiletés d'atténuation allant de 31 à 44 dBA en laboratoire pour les fréquences de 1,000 Hz et plus. Les montures de lunettes de sécurité passées sous les coussins du protecteur réduisent cependant la protection qui passe alors de 25 à 34 dBA. Comme le port de lunettes protectrices est obligatoire pour la plupart des postes de travail dans l'industrie minière, des études sur le terrain dans les mines ont démontré que la protection réelle obtenue par des protecteurs supra-auriculaires peut ne pas dépasser 10 dBA. Les relevés effectués à Falconbridge Ltée, rapports 86-58, 86-59, 86-60, 86-61 avec un résumé final dans 86-88, illustrent la validité de tels travaux. La figure 1 (voir page 5) illustre l'atténuation en dBA (base OSHA) des protecteurs supra-auriculaires en usage dans les mines, où cette dernière est comparée au niveau acoustique pondéré en dBA (décrit différemment dans les rapports comme $L_{eq}(60s)$; L_{OSHA} ou $L_{Avg.}$). La ligne d'atténuation requise est illustrée en assumant que les niveaux acoustiques moyens persistent tout au long de la période de 8 heures et que des bouchons d'oreilles ne sont pas utilisés. Cette figure suggère que la moitié de la population des mineurs n'est pas protégée au niveau légal requis. Toutefois, aucune de ces deux hypothèses n'est vraie et il est fort probable qu'une proportion largement supérieure à la moitié se trouve protégée au niveau requis. La principale raison de la faible performance des protecteurs supra-auriculaires en pratique découle d'un mauvais ajustement, la force du ressort étant souvent inadéquate, principalement chez les individus ayant un faible tour de tête. L'emphase a été mise sur la mesure et le contrôle de la force de serre et le besoin d'ajuster les supports des protecteurs au tour de tête. Des recommendations basées sur ces relevés ont donc été faites, afin d'améliorer les programmes de contrôle pour la protection de l'ouïe.

Les relevés sonores constituent un recueil d'informations. Les relevés détaillés, utilisant la technique d'enregistrement des données, constituent l'essentiel des volumes 3 et 4, et contiennent de l'information précieuse pour tous ceux qui entreprennent des programmes de contrôle du bruit dans des opérations minières. Près de 700 jours-hommes ont été enregistrés lors des relevés détaillés. Il est ainsi possible de constater que la distribution d'exposition des mineurs au bruit varie, au cours de la période de travail, de presque constante à très variable. Dans les mines, 262 des 432 périodes de travail enregistrées l'ont été à l'aide de l'audio-dosimètre en niveau relatif à l'exposition permise. Les valeurs les plus fortes indiquaient un dépassement du seuil de 40 fois, signifiant une protection de l'ouïe de l'ordre de 28 dBA d'atténuation. Cette atténuation serait encore supérieure si les nouveaux standards proposés par OSHA étaient utilisés comme base au lieu des règles actuelles (au moment où les rapports étaient rédigés). Dans les usines et ateliers de surface, seulement 13 des 250 périodes de travail enregistrées l'ont été à l'aide de l'audio-sonomètre. La valeur la plus forte requerrait une atténuation de l'ordre de 10 dBA pour assurer la protection légale de l'ouïe.

Les travaux de contrôle du bruit ont été entrepris sur des foreuses à percussion de poids léger à moyen, sur les foreuses à diamant et sur les systèmes d'échappement des moteurs diesels. Les études sur les foreuses à diamant ont démontré un besoin d'investigation approfondie de toutes les sources de bruit, quatre sources majeures ayant été identifiées. La réduction d'une seule source résulterait en une atténuation à peine discernable du niveau acoustique moyen, à savoir 1 dBA. Elle pourrait cependant modifier la qualité sonore de façon appréciable.

Les niveaux sonores élevés mesurés dans les mines mettent l'emphase sur le besoin de travaux importants, afin de réduire le bruit du matériel minier. Il est probable qu'il faudra éventuellement limiter l'exposition des travailleurs à des bruits n'excédant pas 85 dBA et que l'usage de protecteurs auriculaires devienne une condition de travail indésirable, à éliminer.

L'étude contractuelle sur les vibrations a démontré que les foreuses manuelles verticales et sur béquille exposaient le mineur à des niveaux vibratoires suffisants pour induire le phénomène de Raynaud (insensibilité de la main) chez plus de la moitié de la population sur une période allant de 1 à 4 ans. Elle a aussi permis de démontrer que les isolants vibratoires permettent de réduire la transmission des vibrations à la main et suggéré de développer des poignées isolant les vibrations et de les adapter aux foreuses à percussion. Ces relevés ont aussi identifié des sites où les vibrations corporelles excédaient les directives dans les usines et ateliers de surface. Les véhicles souterrains à moteur diesel ne furent pas examinés.

Le rapport 73-17, dans la section "divers" du volume 6 expose bien les problèmes de bruit et vibrations dans les mines. Les sujets abordés sont la mesure du bruit et des vibrations, les standards d'exposition au bruit et aux vibrations, les sources de bruit et de vibrations, et les méthodes de contrôle.

Il faut enfin mentionner que plusieurs des rapports couvrent plus d'un sujet et qu'ils n'ont pas de renvoi mutuel. Ils sont inclus dans le manuel qui correspond au principal aspect étudié.

Les pages des rapports n'ont pas été renumérotées. Pour mieux localiser chaque rapport, une page rouge est insérée au début de chacun. Chaque rapport est numéroté dans le coin supérieur droit et contient, en plus, son titre propre et la description du contenu, ainsi que son lieu d'édition lorsqu'il ne s'agit pas d'un rapport divisionnel. Un résumé français est compris avec chaque rapport.

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73-157 M. Savich

Production, characteristics and abatement of noise from light and medium rock drills

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Bruit de fonctionnement de perforatrices de poids léger et moyen : production, caractéristiques et réduction

par

Miron Savich*

RÉSUMÉ

Des travaux de recherche ont été réalisés pour analyser les possibilités de réduction du bruit de fonctionnement de perforatrices de poids léger et moyen.

Une analyse détaillée des solutions théoriques et expérimentales appliquées à des perforatrices de poids léger et moyen a montré que le lien qui existe entre la force, la poussée (augmentation de la pénétration) et le bruit demeure un point d'interrogation. Les principales caractéristiques de deux perforatrices de poids moyen, la perforatrice de type 2 et la perforatrice amortie de type 3, ont été analysées. Pour l'analyse comparative des données sur l'intensité du bruit, on a eu recours à la perforatrice à béquille de type 1.

D'après ces analyses, le bruit de la perforatrice est causé :

- aux fréquences inférieures à 125 Hz, par l'impact entre le piston et le fleuret;
- aux fréquences entre 125 Hz et 2 000 Hz, par l'évacuation d'air des orifices d'échappement; et

- aux fréquences supérieures à 2 000 Hz, par l'impact entre le piston et le fleuret et entre le fleuret et la roche.

L'analyse indique que le système de réduction du bruit des perforatrices au rocher peut être amélioré. Une proposition à cette fin est présentée dans le présent projet de recherche. Pour réaliser ces mesures, l'auteur présente sa propre version d'une chambre sourde, construite exclusivement pour mesurer le bruit produit par des perforatrices de poids léger et moyen selon différentes poussées.

Termes clés : Perforatrice au rocher, amortisseur de bruit, analyse du bruit, chambre sourde.

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Droits de la Couronne réservés.

Production, Characteristics and Abatement of Noise from Light and Medium Rock Drills

by

Miron Savich*

ABSTRACT

Research was conducted to investigate the possibilities of noise abatement in light and medium rock drills.

Detailed analysis of the theoretical and experimental solutions of light and medium rock drills showed that the relationship between force, thrust (penetration increase), and noise remained unresolved. The main characteristics of two medium rock drills, Type 2 rock drill and Type 3 muffled rock drill, were investigated and analysed. For the comparative analysis of noise measurement, the Type 1 feed leg drill was used.

These investigations showed that rock drill noise is generated in the following manner:

- at frequencies below 125 Hz, by the impact between the piston and drill steel;
- at frequencies between 125 Hz and 2000 Hz, by exhaustion of air

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Key Words: Rock Drill, Muffler, Noise Analysis, Anechoic Chamber.

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from the exhaust ports; and

- at frequencies above 2000 Hz, by the impact between the piston and drill steel, and between the drill steel and rock.

Analysis showed that the system for noise abatement in rock drills can be further improved. In this research project, a proposition to achieve this end is given. To perform these measurements, the author gave his own variant of an anechoic chamber, constructed exclusively for the measurement of noise of light and medium rock drills under different power thrusts.

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1. INTRODUCTION

Noise generated by rock drills creates a dangerous acoustical environment in the mining industry. The isolation of man from noise with the aid of mufflers on rock drills of small or medium weight is just the beginning of a solution. The present trend in rock drill design is to increase the power and mechanical efficiency; this also increases the noise.

Improvements in mining operations have been brought about by:

a) increasing the drilling speed;
b) increasing the drilling depth;
c) reducing the noise; and
d) speeding up loading and transportation.

In the development of the rock drill, the following were important (Figure 1):

- the inventors have tended to decrease the drill or bit size because the drilling speed is inversely proportional to the hole diameter;
- the drilling speed and the drilling depth are greatly dependent upon the quality of the material of which the bit and rods are made.

It was clear that these two problems could not be solved separately. An ideal drill with the following characteristics was sought:

a) a good speed in the hardest of rocks and a bit with a long life before re-sharpening; and
b) a steel rod with long service life.

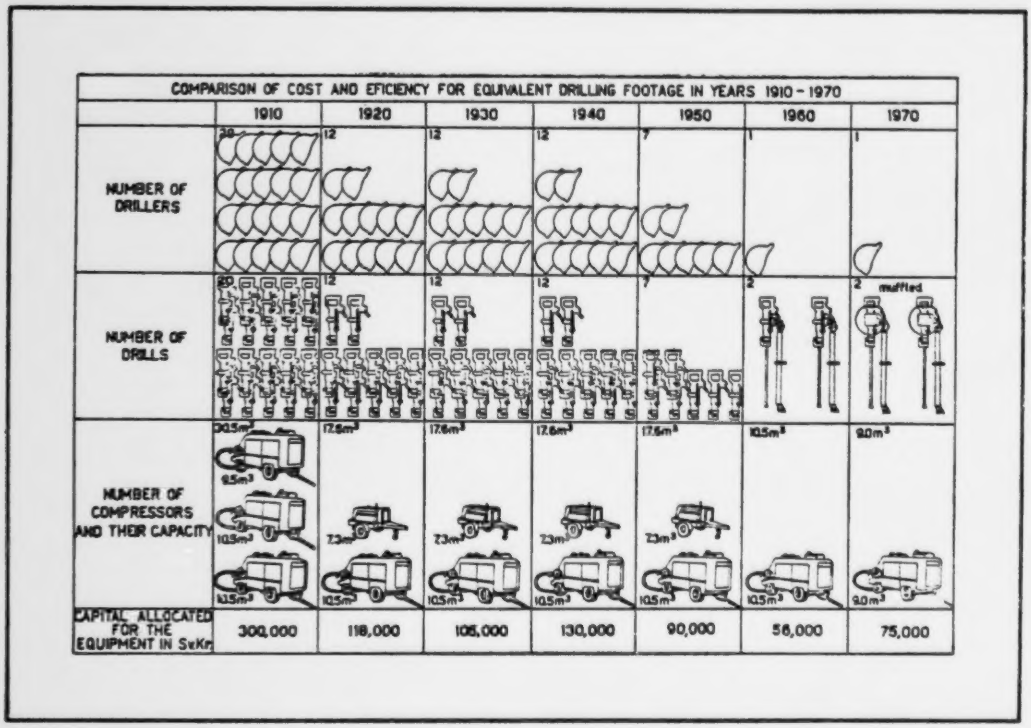


Figure 1: Comparison of Cost and Efficiency for Equivalent Drilling Footage in the Years 1910-1970. (Data by S. Adler and M. U. Savich)

The main advantages of the medium-heavy rock drill (21 to 30 kg) are:

a) great efficiency in combination with the feeding leg and integral drill steel;

b) its universal use for drilling tunnels and other underground mining works;

c) use of standard integral drill steel;

d) small consumption of compressed air; and

e) reduction of dust, vibration and noise.

Since silencers that cut noise energy by 75% are now built into light and medium rock drills, these machines have a much lower noise level.

The objectives of this research project are:

1. to give a technical proposal for the ideal solution for the suppression of noise from rock drills, and
2. to develop methodology to provide quantitative data on the intensity of noise generated.

2. SURVEY OF NOISE PRODUCED BY ROCK DRILLS

In the past 25 years, great effort has been put into mechanization, increase in drilling speed, development of mining methods, and increased safety, etc., but little has been done to reduce the degree of noise. Implementation of features to reduce noise will take time, due to costs involved.

A voluminous literature survey and a review were made of technical and technological solutions for all modern rock drills manufactured. The investigators (references 1 to 15) made important efforts to reduce the noise in rock drills.

Even though many muffled rock drills are on the market, few technical data are available about their performance, details of construction, and the factors that influenced their design. Table 1 illustrates the types of rock drills and their possibility of reducing the noise. As the principle of the problem is the same, more detailed designs for noise reduction at the source will be shown.

Table 1

Common Rock Drills

Rock Drill Data	Light	Medium	Heavy	Down the Hole
Net weight (kg)	21-30	30-50	50	12-218
Piston diameter (mm)	50-75	75-100	100-150	40-150
Length of stroke (mm)	20-70	35-70	80	100-200
Bore (mm)	22-45	35-70	70-90	65-230
Drill steel (mm)	22.2-25.4	22.2-12.7	31.75-44.45	Drill tubing
Drilling speed (cm/min)	15-70	10-90	20-110	5-20
Maximum depth (m)	5	7-12	25	100
Air consumption at 59 N/cm^2 (m^3/min)	1.5-4.5	4.5-8	12-18	2.5-6
Noise reduction	Silencer	Silencer	Silencer and control inside acoustic enclosure	
Noise (dBA)	112-118		116-123	

The Joy Al-60 Air Leg has a higher drilling speed and quieter operation.(Figure 2.1). Joy have made a muffled type cylinder (reactive muffler) that leads to a substantial reduction in the noise level (16).

Ingersoll-Rand (Figure 2.2) have introduced a new muffled version of the "300 series" jack drill and stoper. These muffled drills are substantially quieter than the non-muffled machines. They reduce the all-pass

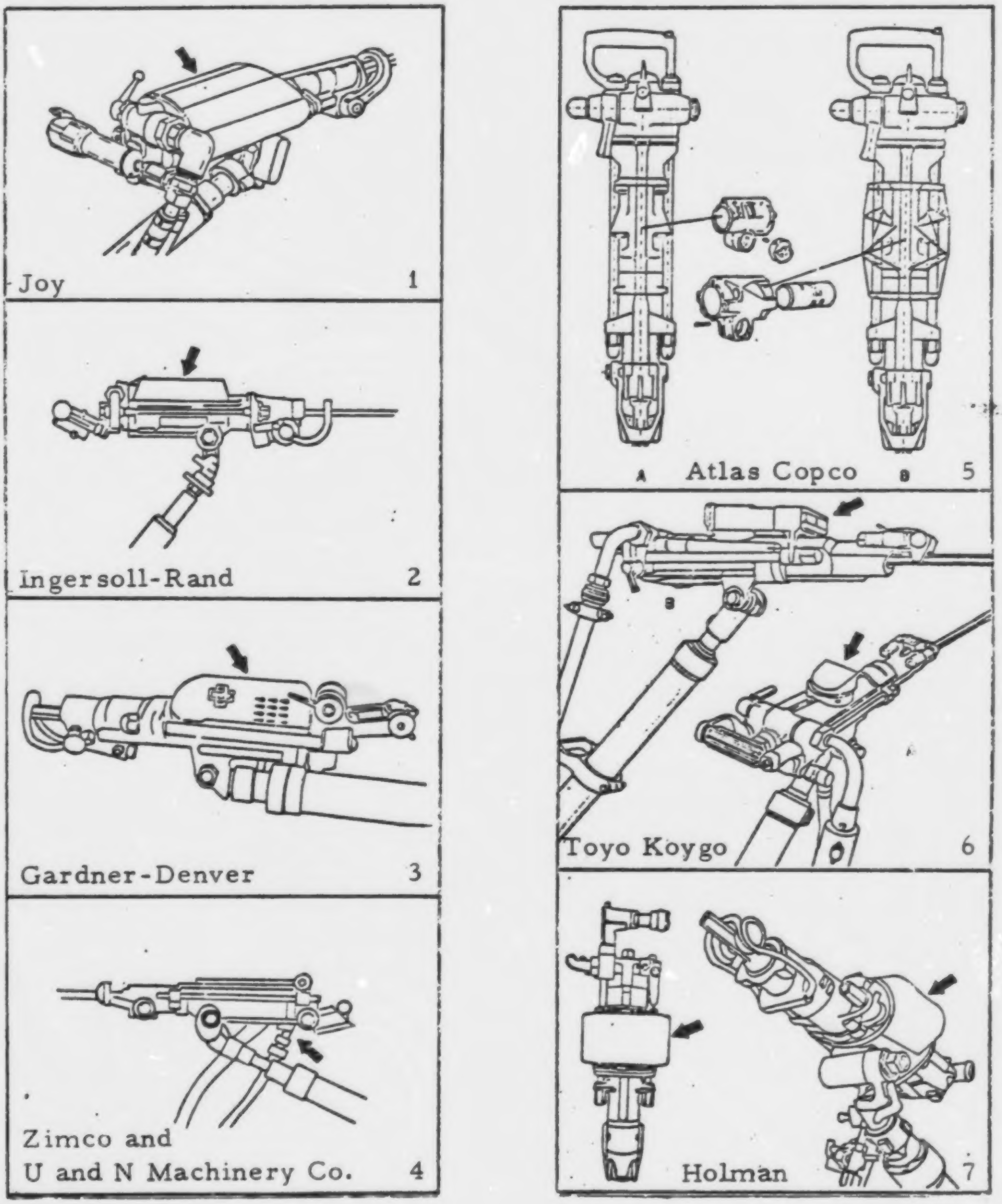

Joy
1
Ingersoll-Rand
2
Gardner-Denver
3
Zimco and
U and N Machinery Co.
4
A
Atlas Copco
B
5
B
Toyo Koygo
6
Holman
7

Figure 2: Main Rock Drills on the Canadian Market.

1. Joy Al-60 Air Leg (Muffled).
2. JR 300 M Jackdrill.
3. Feed Leg Muffled Drill (S63F).
4. S 240 M Air Leg.
5. A- Rock Drill Type Lion (BBC24W)
   B- Rock Drill Type Lion (BBC25W)
6. A- Leg Drill TY 24 LD.
   B- Leg Drill TY 24 L.
7. Silver 303 Air Leg Drill.

noise level by a significant 2 to 8 decibels (17).

Gardner-Denver (Figure 2.3) have an integrally-muffled cylinder on the upper side and the air exit almost on the rear side of the cylinder (18).

However, the U and N S-240M combination drill (stoper and air leg) has a muffled cylinder on the lower side and the air exit on the upper front side (Figure 2.4) (19).

The patented silenced cylinder by Atlas Copco is based on the idea that exhaust air produces less noise when split up into many small jets (20). Conventional drills have two large exhaust ports which result in the sudden release of the working air. The Atlas Copco silenced cylinder has rows of small holes on the inside which allow gradual reduction of cylinder pressure (Figure 2.5 A, B). This special cylinder cuts noise energy by 75%. The curve for the sound-pressure level of this rock drill does not enter the dangerous sector.

The Leg Drill TY 24-LD (Figure 2.6A) by Toyo Kogyo Company Ltd. is equipped with nose (directivity factor) and vibration deadening devices (21). A very practical side of the rock drill is that the directivity factor is determined by the position of the nose; the total or partial noise reflection in the underground or surface mining area can be avoided. The difference in noise between the maximum and that at the miners' position is 5 to 8 decibels.

Leg Drill TY 24 L (Figure 2.7B) is the more modern version of TY 24 LD. The nose is substituted by a built-on resonating chamber. The idea is new and very interesting.

The muffler for Holman's (Figure 2.7) Silver 303 Air Leg Drill is produced in a light yet durable synthetic material (1 kg), formed with cleanly moulded contours so as not to impede the operator (22). For easy servicing, two clips only are used to secure the muffler to the cylinder body of the drill. Tested in conditions established under C.A.G.I. PNEUROP Code (23), a noise-level reduction of 5 dBA was recorded for the muffled version operating at the normal working pressure of 55 N/cm^2.

Each solution has its advantages and disadvantages; only by actual measurements can the most beneficial results be determined.

Still more important is the fact that sound-energy levels are most reduced in those frequency ranges considered most annoying and injurious to the hearing. Muffling is accomplished with no loss in drill performance and with only a slight increase in the overall weight.

The most characteristic data on the use of mufflers in the lighter or medium rock drills have been discussed. However, a certain number of machines have been developed which, with success, can take over a part of the work of the rock drill, or replace it completely when the work is done in softer rock.

3. PHYSICS OF THE ROCK DRILL, TYPE 2 AND TYPE 3

In reporting noise measurements it is normally necessary to specify the operational characteristics of the machine and to give a description of its installation.

The rock drill is manufactured in two versions, Type 2 and Type 3, the latter being provided with a silenced cylinder. By combining a rock drill and a pusher feed, a well-balanced and easily handled unit is obtained. The weight of the pusher feed is 14.9 kg (33 lb), the length is 1660 mm (65 in.). The effective length of feed is 1300 mm (51 in.). The main data are given in Table 2.

Table 2

Principal Data on Rock Drills, Type 2 and Type 3

	Type 2		Type 3	
Piston diameter	70 mm	2.75 in.	70 mm	2.75 in.
Length of stroke	70 mm	2.75 in.	70 mm	2.75 in.
Impacts/min at 60 N/cm^2 (85 psi)	2050		2050	
Weight	29.1 kg	64 lb	29.7 kg	65.5 lb
Total length	770 mm	30.25 in.	770 mm	30.25 in.
Air consumption	4.5 m^3/min	155 cfm	4.5 m^3/min	159 cfm
Hose diameter: Air Water	25.4 mm 12.7 mm	1 in. 0.5 in.	25.4 mm 12.7 mm	1 in. 0.5 in.

3.1 The Working Position of the Rock Drill

It was necessary to check the number of impacts per minute and to determine the speed with which the piston strikes the drill steel in three different working positions of the rock drill (Table 3): horizontal, vertical down, and vertical up.

Conclusions:

1. The acceleration due to gravity is very small compared to the acceleration of the piston so that it does not influence the number of rock drill strokes, regardless of drill position.
2. The noise levels and vibrations in all three cases were the same and because of this, the horizontal position, which is the most practical for work and investigation, was chosen.
3. The coefficient of air resistance in the air holes of the Type 2 and Type 3 rock drill is about 73%. This coefficient coincides with the coefficient of classical rock drills.

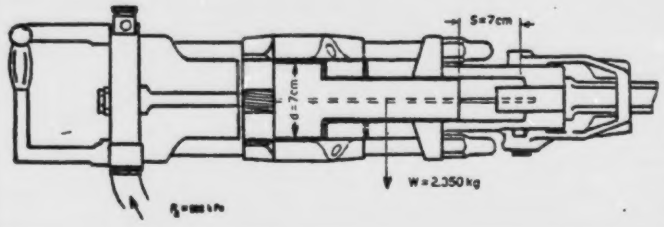
3.2 Rebound of Rock Drills

After each impact the rock drill rebounds, causing an impact which must be received either by the miner or by a pusher feed.

For a clearer presentation of the rebound of the rock drill, two diagrams may be drawn in which the relationships between distance-time and velocity-time are shown (Figure 3). The numbers on the ordinates define the time in milliseconds.

Table 3

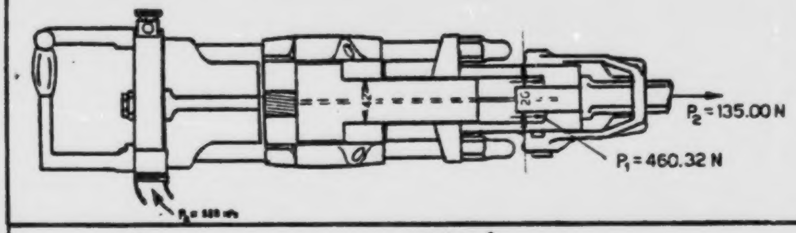
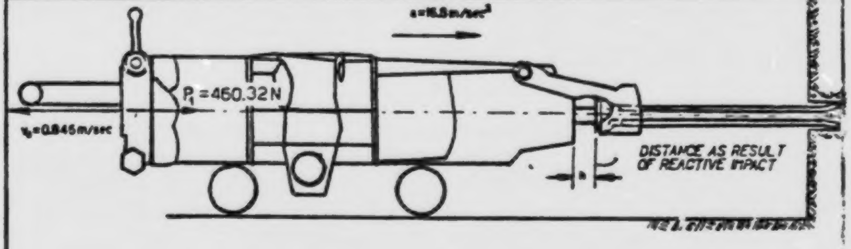
The Working Positions of the Rock Drill

<table>
<tr><td colspan="2" rowspan="2">Rock Drill Type 3
Piston Mass
m = 2.35 kg</td><td colspan="3">
</td></tr>
<tr><td>Horizontal</td><td>Vertical Down</td><td>Vertical Up</td></tr>
<tr><td colspan="2">P [N]
Force</td><td>1654.2</td><td>1654.2</td><td>1654.2</td></tr>
<tr><td colspan="2">a [m/sec^2]
Acceleration</td><td>700</td><td>709.8</td><td>690.2</td></tr>
<tr><td colspan="2">t [sec]
One stroke*</td><td>0.0297</td><td>0.0295</td><td>0.03045</td></tr>
<tr><td rowspan="2">Impacts per Minute</td><td>n (Calculated)</td><td>2020</td><td>2030</td><td>2000</td></tr>
<tr><td>n (Data factory</td><td>2050</td><td>—</td><td>—</td></tr>
<tr><td colspan="2">ν [m/sec]
Velocity**</td><td>9.87</td><td>10.0</td><td>10.35</td></tr>
</table>

* Forward and back.
** At the moment of impact.

Table 4

Rebound of Rock Drill

Rock Drill Type 3 Rock drill mass $m = 27.35$ kg (without a piston and drill steel)	 42 20 $P_2 = 135.00$ N $P_1 = 460.32$ N  $a = 16.8$ m/sec^2 $P_1 = 460.32$ N $v_0 = 0.845$ m/sec DISTANCE AS RESULT OF REACTIVE IMPACT h

a_1 [m/sec^2]	Acceleration back	60
S_1 [mm]	Return stroke travel	5.965
v_0 [m/sec]	Return velocity (backwards velocity)	0.846
P_1 [N]	The force on the round piston	460.32
P_2 [N]	The force pushes the bit in to stone	135.0
a_2 [m/sec^2]	Rock drill moves forward (acceleration)	16.8
t_x [sec]	Time of backward motion	0.0503
h [mm]	The distance travelled in this time	21.3

In the distance-time diagram are marked the values t_1 and the corresponding distances.

At point b, the piston strikes the drill steel and then begins its backward movement. The curve bc corresponds to the values of the backward motions of the rock drill.

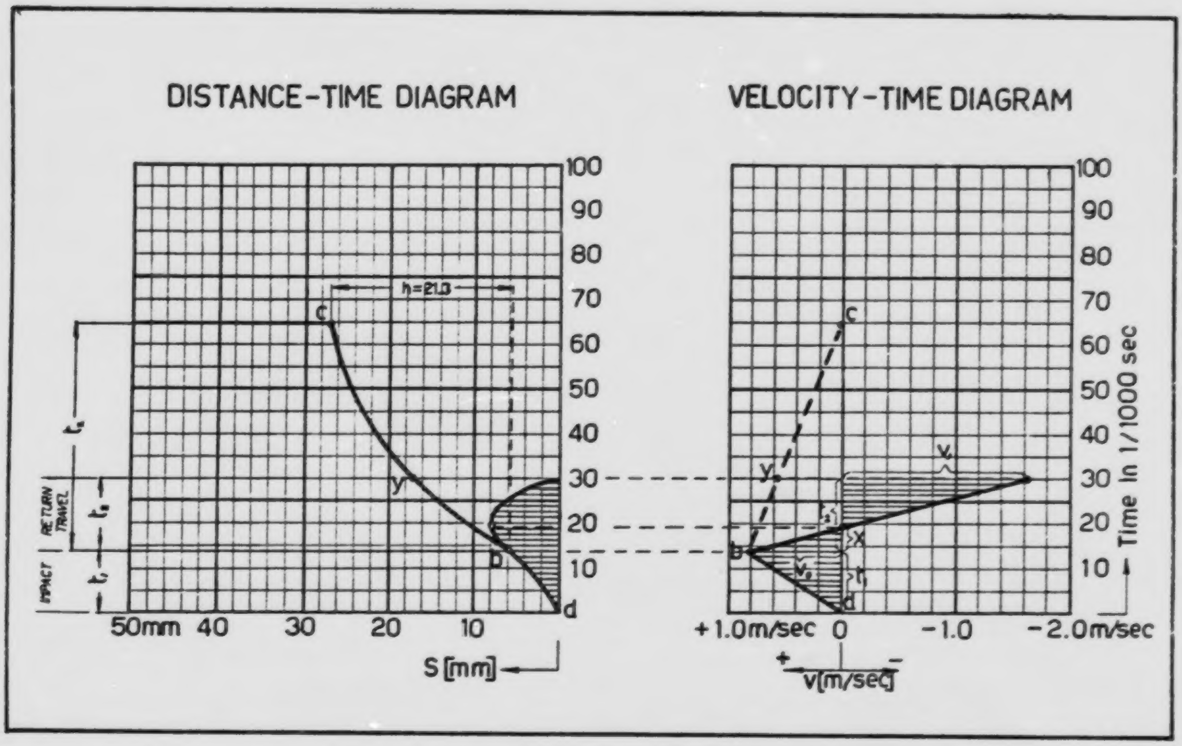


Figure 3: Distance-Time and Velocity-Time Diagrams (Type 3 Rock Drill).

In the velocity-time diagram, the corresponding function is shown as the straight line bc. At point y, the piston has finished its return travel and has again begun its impact travel, by which the drill is again accelerated backwards.

In order to prevent this, a force must be used which will oppose the backward motion. The pushing back acts on the drill only during the time, t_2, of return travel of the piston. From the velocity-time diagram (Figure 3B), we see that the velocity, ν_0, of the rock drill at point b must be decreased to zero. Let this interval of time be x. The return travel of the piston lasts t_2 seconds, and, at the end of this interval of time, the rock drill has to strike on the shank of the drill rod with a still-unknown final velocity, ν_1.

As the travel forward has to be equal to the travel backward in the diagram of velocity-time (Figure 3 B), the corresponding surfaces which are noted by signs plus and minus have to be equal. Then,

$$\frac{1}{2}\nu_0 (t_1 + x) = \frac{1}{2}\nu_1 (t_2 - x). \qquad \text{(Equation 1)}$$

From the similarity of the triangles, it follows that,

$$\nu_0 : x = \nu_1 : (t_2 - x). \qquad \text{(Equation 2)}$$

From these equations with two unknown variables, we obtain

$$x = \frac{t_2^{\,2}}{t_1 + 2t_2}\ . \qquad \text{(Equation 3)}$$

From Equation 3 it follows that

$$\nu_1 = \frac{\nu_0}{x}(t_2 - x), \qquad \text{(Equation 4)}$$

and in our case,

$t_1 = 0.0141$ sec, $t_2 = 0.00156$ sec, and $\nu_0 = 0.846$ m/sec.

If these values are introduced in the equations for x and ν_1 (Equations 3 and 4), we obtain

$$x = 0.00537 \text{ sec, and}$$

$$\nu_1 = 1.6143 \text{ m/sec.}$$

These values, when plotted on the velocity-time diagram, produce two triangles with equal areas. For the value of "x", we then calculate the value for the acceleration, "a", which has to push back on the rock drill handle.

At the end of $x = 0.00537$ sec, the velocity of the return motion has decreased from $\nu_0 = 0.846$ m/sec to zero,

$$\nu_0 = xa \text{ or } a = 158 \text{ m/sec}^2. \qquad \text{(Equation 5)}$$

For a rock drill of mass $m = 27.35$ kg to be able to move with this acceleration, the force required is

$$P = ma \cong 4320 \text{ N.} \qquad \text{(Equation 6)}$$

The force (Table 4) of $P_1 \simeq 460$ N acts on the round piston surface. Thus, the force which should act on the rock drill handle is,

$$F = P - P_1 \approx 3860 \text{ N.} \qquad \text{(Equation 7)}$$

This is a large force and the calculation, as performed, confirms the known case with the pneumatic rock drill. Its handle has to be pushed immediately when it begins the work, otherwise a greater force is needed for the rock drill to return to its normal working position.

In the distance-time diagram (Figure 3 A), a curve is drawn which represents the force F = 3860 N from the point b. The abscissae are defined by the following formula:

$$S = \nu_0 t - \frac{1}{2} at^2 , \qquad \text{(Equation 8)}$$

where $t = t_1 + x$, $\nu_0 = 0.846$ m/sec, and $a = 158$ m/sec^2 .

Thus, the values which were used to plot the shaded surfaces of the diagram were obtained. The pressure acting on the rock drill during the time t_1 of impact travel and the time t_2 of the return travel of the piston will not be considered because it is more important to explain the laws of work efficiency of Type 2 and Type 3 rock drills.

3. 3 Efficiency

For the same interval of time and the same impressed forces, the corresponding mass velocities are inversely proportional to the masses. When the masses are moving with velocities ν_1 and ν_2, they will have their ratio of corresponding kinetic energies:

$$\frac{A_1}{A_2} = \frac{m_1 \nu_1^2}{m_2 \nu_2^2} \qquad \text{(Equation 9)}$$

As

$$\frac{m_1}{m_2} = \frac{\nu_2}{\nu_1} \ , \quad \text{it follows}$$

$$\frac{A_1}{A_2} = \frac{\nu_1}{\nu_2} \ . \qquad \text{(Equation 10)}$$

Thus, it follows that, for equal intervals of time and equally impressed forces, the kinetic energies of both bodies are proportional to the final velocities. These laws can be applied to the Type 2 and Type 3 rock drills. The rock drill piston has a weight $W_1 = 2.35$ kg and its body has a weight $W_2 = 27.35$ kg. Compressed air accelerates the piston forward and the body backward. Previously, we calculated the velocity $\nu_1 = 9.87$ m/sec at which the piston strikes the steel rod. The velocity ν_2 of the returning motion of the body may be calculated from the above equation as follows:

$$\nu_2 = \nu_1 \frac{m_1}{m_2} = 0.848 \text{ m/sec.} \qquad \text{(Equation 11)}$$

The compressed air does two things: (1) it pushes the piston forward and (2) it pushes the body backward. The first effect is useful, but the second is harmful because the reactive shock may harm the worker. The ratio of the effects is expressed by the equation:

$$\frac{A_1}{A_2} = \frac{\nu_1}{\nu_2} = \frac{9.87}{0.848} .$$

The ratio of work A_1 to the overall work is then:

$$\frac{A_1}{A_1 + A_2} = 0.92 . \qquad \text{(Equation 12)}$$

From this it may be concluded that 92% of the compressed air is transformed to impact energy, while 8% is lost in the reactive drill body's stroke (24).

The return motion can be prevented by applying a greater force on the rock drill. If the final velocity of the returning motion is thus decreased to $\nu_2 = 0.2$ m/sec, it follows that,

$$\frac{A_1}{A_2} = 49.3 \qquad \text{(Equation 13)}$$

$$\frac{A_1}{A_1 + A_2} \cong 0.98 \qquad \text{(Equation 14)}$$

This means that the impact effect would increase from 92 to 98% and the loss, because of the return stroke, would decrease from 8 to 2%.

Since the weight differences between rock drills Type 2 and Type 3 are small, the results for both types are the same.

Conclusion:

The silenced Type 3 rock drill has the same basic momenta as the unsilenced Type 2 rock drill. Both types of drill have the same efficiency, namely, 92%. With increasing force on the rock, the impact efficiency can be increased. In this case it is clear that we can expect a noise increase.

4. NOISE MEASUREMENT PRACTICE

4.1 Measurement of Noise Emitted by Rock Drills

An anechoic chamber has been constructed exclusively for the noise measurement of light and medium rock drills under different thrusts (power pressures)(25). Exact measurements of the thrust on the drill and the drilling velocities were made. Calibration of the anechoic chamber predicts a cut-off frequency at 400 Hz.

In this project, the initial measurements were made with the weight M2 = 30 kg. Final measurements for M10 = 113.20 kg were used because this corresponded to the weight of the rock drill (Figure 3).

The sound sources under test were: Feed Leg Drill Type 1, Rock Drill Type 2, and Rock Drill Type 3.

The location of the microphone and of the rock drill in the anechoic chamber are shown in Figure 4. The hypothetical sphere which is used to determine the space-average of the sound-pressure squared is centered about the acoustical centre of the sound source. Its radius is at least two major source dimensions but not less than 2 feet. The surface of the test sphere is at least $\lambda/4$ distant from the absorbent surfaces of the anechoic chamber, where λ is the wavelength of sound corresponding to the centre frequency of the lowest frequency band of interest (26).

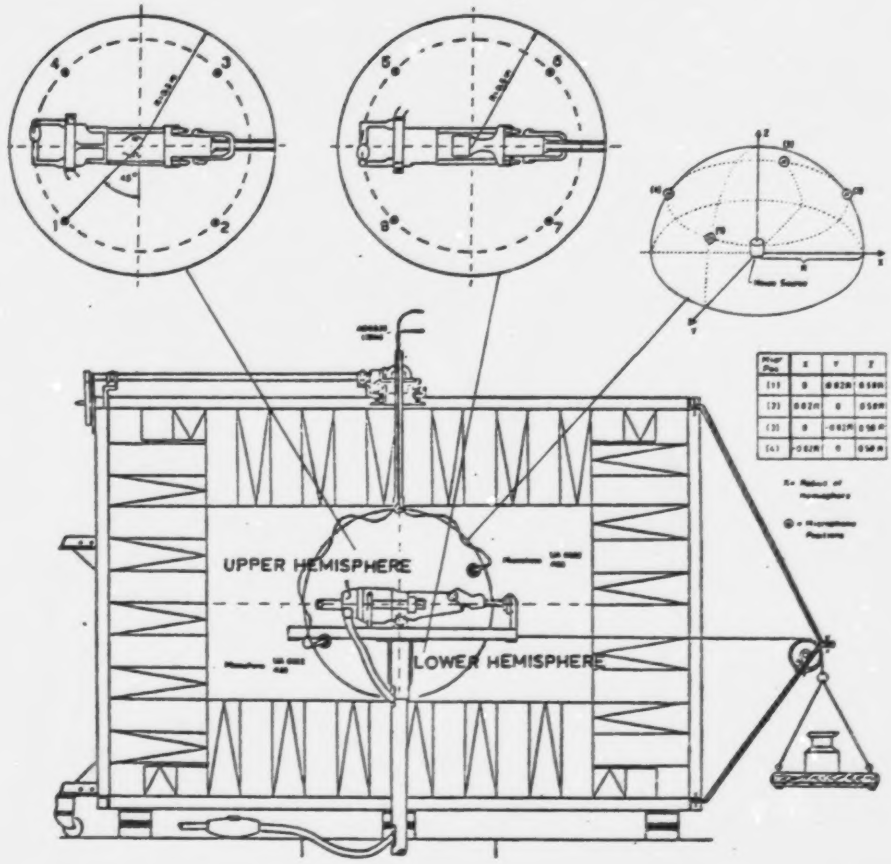
The space-time average pressure level, $<\overline{SPL}>_H$, over the test surface of a hypothetical hemisphere is (27):

$$<\overline{SPL}>_H = 10 \log_{10} \frac{1}{2\pi r^2} \left[a_1 \text{ antilog } \frac{<SPL_1>}{10} + a_2 \text{ antilog } \frac{<SPL_2>}{10} \right.$$

$$\left. \ldots a_n \text{ antilog } \frac{<SPL_n>}{10} \right] \qquad \text{(Equation 15)}$$

where $2\pi r^2$ is the total surface area of the test hemisphere;

$<SPL_1>$, $<SPL_2>$, $<SPL_3>$, . . . $<SPL_n>$ are the time-average sound-pressure levels, measured at a suitable array of points 1, 2, 3, . . . n on the surface of the test hemisphere; and


1
2
3
4
5
6
7
8
40°
UPPER HEMISPHERE
LOWER HEMISPHERE

Measurement	1	2	3	4	5	6	7	8	9	10	11
Weights (kg)	22. 1	30. 0	40. 0	50. 0	60. 0	70. 0	80. 0	93. 2	103. 2	113. 2	123. 2

Figure 4: The Location of the Drilling Rig and the Microphone in the Anechoic Chamber.

$a_1, a_2, a_3, \ldots a_n$ are the respective areas associated with these n points.

When $a_1 = a_2 = a_3 = \ldots a_n$, then the total surface area of the test hemisphere, $2\pi r^2 = na$. In this case, Equation 15 becomes:

$$<\overline{SPL}_H> = 10 \log_{10} \text{ antilog } \frac{<SPL_1>}{10} + \text{antilog } \frac{<SPL_2>}{10} + \text{antilog } \frac{<SPL_n>}{10} - 10 \log_{10} (n\,a) \,. \qquad \text{(Equation 16)}$$

An array of 8 measuring points on the surface of the test sphere was used, 4 of which were on the upper hemisphere and 4 on the lower hemisphere. The coordinates of these 8 measuring points are given in terms of Cartesian coordinates (x, y, z) (Figure 4).

Putting n = 8 (or n = 4, for the hemisphere) in Equation 16, the space-average sound-pressure level over the surface of the test sphere is:

$$<\overline{SPL}_s> = 10 \log_{10} \frac{1}{8} \text{ antilog } \frac{<SPL_1>}{10} + \text{antilog } \frac{<SPL_2>}{10} + \ldots \text{antilog } \frac{<SPL_8>}{10} \qquad \text{(Equation 17)}$$

or, over the hemisphere, is:

$$<SPL_H> = 10 \log_{10} \frac{1}{4} \text{ antilog } \frac{<SPL_1>}{10} + \text{antilog } \frac{<SPL_2>}{10} + \text{antilog } \frac{<SPL_4>}{10} \ \ldots \qquad \text{(Equation 18)}$$

The same equation uses CAGI-PNEUROP Test Code for calculation of the average sound level (dBA) (or band-average pressure level in decibels).

The measurements should be made with the machine operating under rated conditions (normal operating conditions); it should preferably be mounted either on vibration isolators, which ensure no undesired transmission of vibrations to connected structures that might amplify the sound radiation, or under conditions similar to those recommended by the manufacturer for normal installation.

All the sound-pressure levels measured should be corrected for the influence of background noise before they are applied to the formulae given here.

4.2 Description of Program

The program is based on the test codes (23, 26, 28). In the event of revisions, it is noted in the text where and why the deviations occurred.

a) The number of measurements in the hemisphere is reduced to 4 for practical reasons (ISO called for at least 4 in 1968 and at least 6 in 1970). CAGI-PNEUROP Test Code recommends 4. We have proved experimentally and mathematically that 4 measurements are enough.

b) Evaluation of collected data. The following calculations were performed:

1. Time-average of sound-pressure level in octave band for measuring preferred frequencies, 31.5, 63, 125, 250, 500, 1000, 2000, 4000,

and 8000 Hz. A network is used for octave-band and overall measurements.

2. Spatial average of sound pressure level for each measuring position, after Equations 17 and 18.

3. The sound-pressure level in octave bands (CAGI - Test Code) is computed according to the following relation:

$$L_{oct} = 10 \log (10^{0.1 L_1} + 10^{0.1 L_2} + 10^{0.1 L_3}) \text{ (db)} \qquad \text{(Equation 19)}$$

where L_1, L_2 and L_3 are the respective 1/3-octave sound-pressure levels.

4. Directivity index and directivity factor (27 and 29).

c) Printout of full measurement report, with result of calculations according to (a) and (b).

4. 3 Accuracy of Measurements

In order that noise may be controlled effectively, it is primarily necessary to be able to measure the noise emitted by machines objectively, according to internationally accepted procedures (ISO R495).

By selecting the number of measurements and their accuracy, it is accepted that eight measurements for the areas on a hypothetical sphere around the source are enough. The time average measurement, SPL, for 45 microphone locations and for 8 microphone locations is practically the same for the feed leg drill Type 1; there is a small difference between rock drill Type 2 and Type 3 at 2000 Hz.

Determination of the SPL for 45 microphone locations by using the statistical method and the time-average SPL of 45 microphone locations shows almost the same results. The differences are at 63.5 Hz which can be explained theoretically because of the cut-off frequency of the anechoic chamber, and at 8000 Hz, because of the pressure characteristics of the half-inch microphone.

4.4 Sound-Pressure Level (dBA) on a Hypothetical Sphere around the Rock Drills

For all three rock drills, the statistical data were used to produce Figures 5A and 5B. The reliability of the basic data, using a statistical method, was confirmed by a similar assessment using a graphical method. The normal curve can be constructed.

If we compare the normal curve of the Type 1 feed leg drill (45 measurements) to that of the Type 2 rock drill (46 measurements), we see that both drill hammers have almost the same noise extensity. If the efficiency of both rock drills is the same, then what has to be proved by later investigations is that Type 1 feed leg drill has an advantage over the Type 2 rock drill, with respect to noise level.

Meanwhile, by comparing the Type 2 rock drill unmuffled (46 measurements) with the Type 3 muffled (45 measurements) of the same efficiency, it can be seen that the intensity and extensity differ (Figure 5B).

The diagram dBA vs frequency in % is constructed (Figure 5B) to obtain an exact picture of the displaced values of SPL in dBA. From the

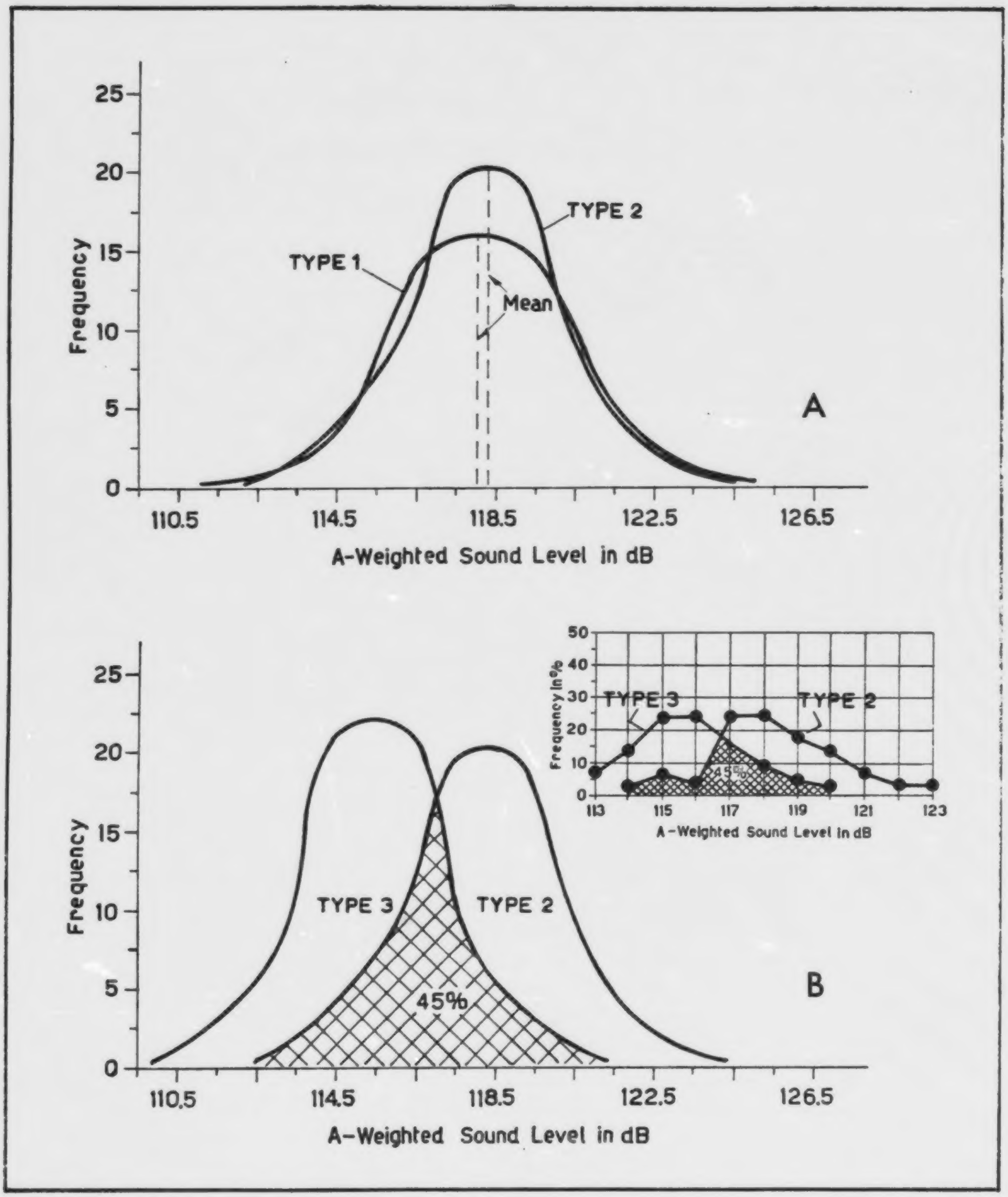


Figure 5. A. The Normal Curve of the Feed Leg Drill Type 1 and the Rock Drill Type 2.
B. The Normal Curve of the Rock Drill Type 2 and Type 3.

diagram, it can be seen that the muffler was the cause of the curve being displaced for a reduction of 3 dBA, because the same result is obtained from the integral of the surfaces as from the normal curve, Type 1 and Type 2 (Figure 5B). The five men questioned all agreed that the Type 2 rock drill was easier on their hearing.

4.5 Noise of the Rock Drills without Drill Steel

A comparative analysis of the noise spectrum was made for the following machines: Feed leg drill Type 1, Rock drill Type 2, Rock drill Type 3, and Rock drill Type 3 - Exhaust. From Table 5, it can be seen that the feed leg drill Type 1 is heavier, the piston is lighter, and it makes fewer impacts per minute, compared to rock drills Type 2 and 3; however, it makes much more noise.

Table 5

Principal Data on Feed Leg Drill Type 1 and Rock Drills Type 2 and Type 3

Type	Weight (kg)	Piston Weight (kg)	Impacts* per min	Sphere (dBA)	Upper Hem. (dBA)	Lower Hem. (dBA)
1	29.934	2.155	1.980	119.03	120.51	116.77
2	29.100	2.350	2.050	114.35	114.97	113.04
3	29.700	2.350	2.050	110.10	111.54	107.92

* At 60 N/cm^2.

The diagrams (Figure 6) indicate the values for the span of 250 Hz to 8000 Hz. The greater values in this span are for the feed leg drill Type 1, which confirms that the piston construction is not well balanced.

A comparison of rock drills Type 2 and Type 3 shows that the muffler construction on the latter is very effective for the frequency span of 125 Hz to 5000 Hz. In the vicinity of 5000 Hz, the noise is increased in Type 3 (muffled). This can be explained by the smothering which takes place.

Of special interest are the results of the rock drill Type 3 with a muffled exhaust. At all frequencies, there was an attenuation of the noise levels. It can be concluded that the greater part of the noise is caused by the outlet stream of compressed air from the nose of the rock drill. This confirms the high quality of construction in this rock drill. At frequencies of 1000 Hz to 2000 Hz, the differences between the values (SPL) in the lower hemisphere of the rock drill are at a minimum. Since the construction of the Type 3 and the Type 2 does not differ, this statement is applicable to both rock drills.

4.6 Noise of the Rock Drills with Drill Steel

The sound spectrum was analyzed for the rock drills with and without exhaust. In order to obtain the most probable value of the spectrum, all measurements were computerized with a force on the rock drill of 60.0 kg to 113.20 kg (Figures 7 and 8). These thrusts correspond to the feed leg pressures exerted by the operators.

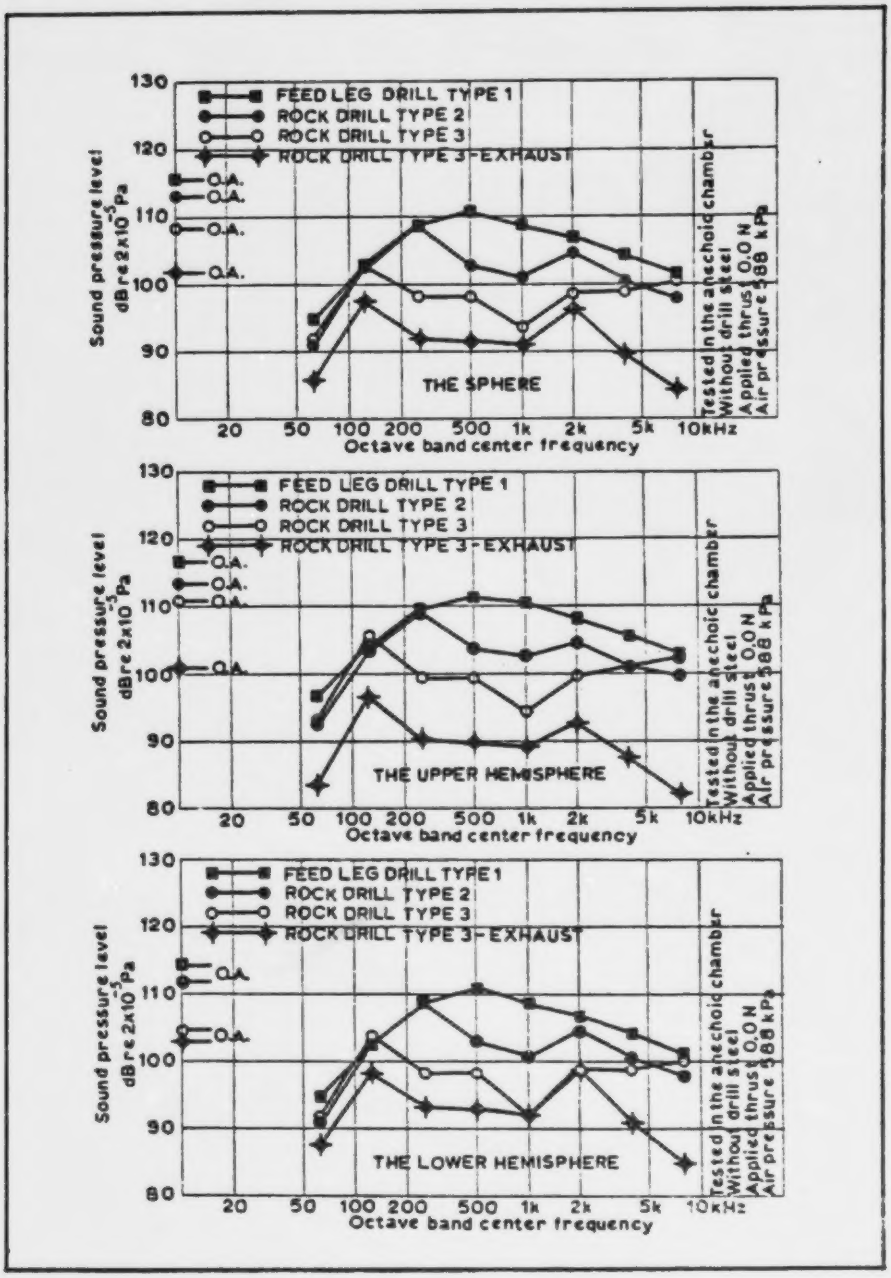


Figure 6: Noise of Rock Drills without Drill Steel.

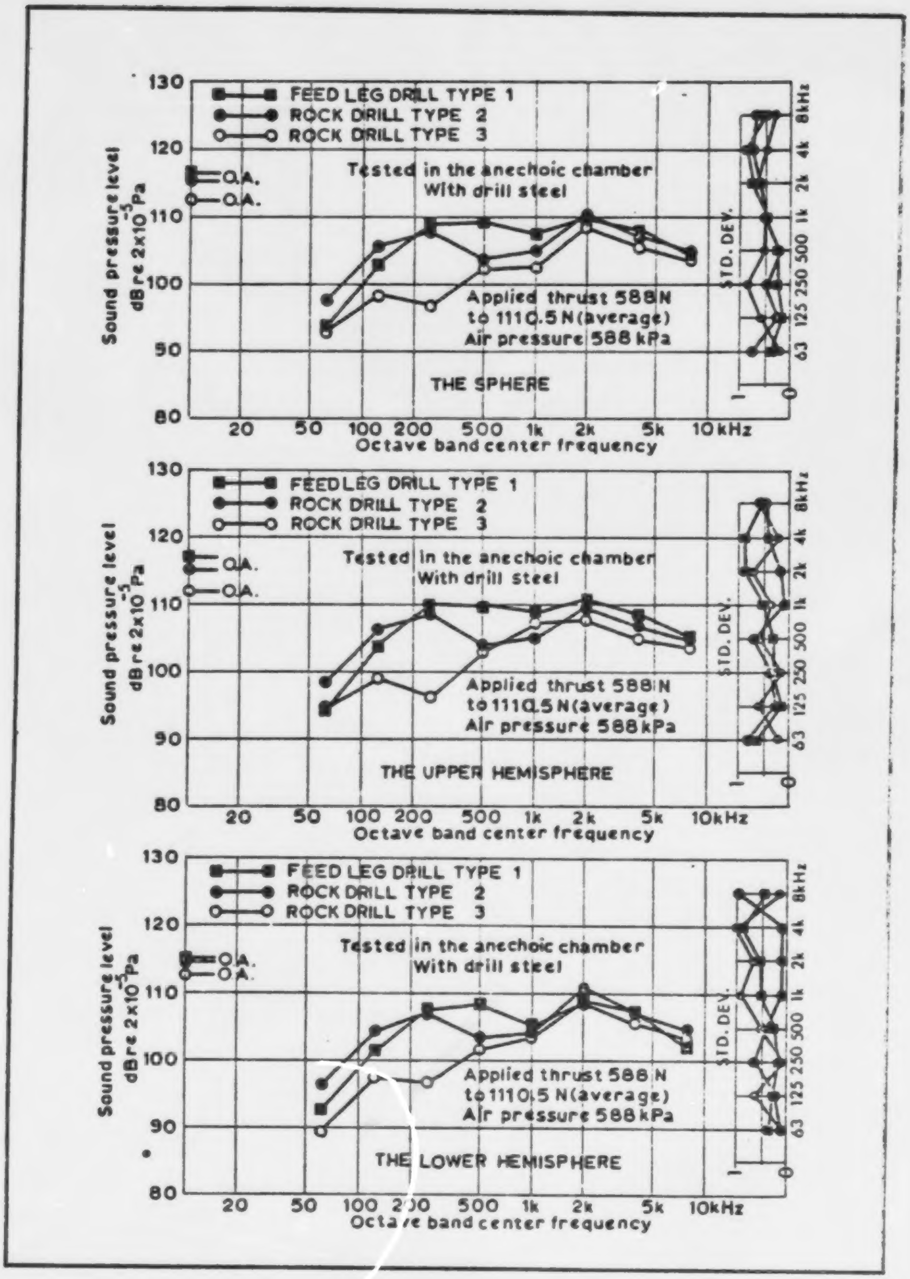


Figure 7: Noise of Rock Drills with Drill Steel.

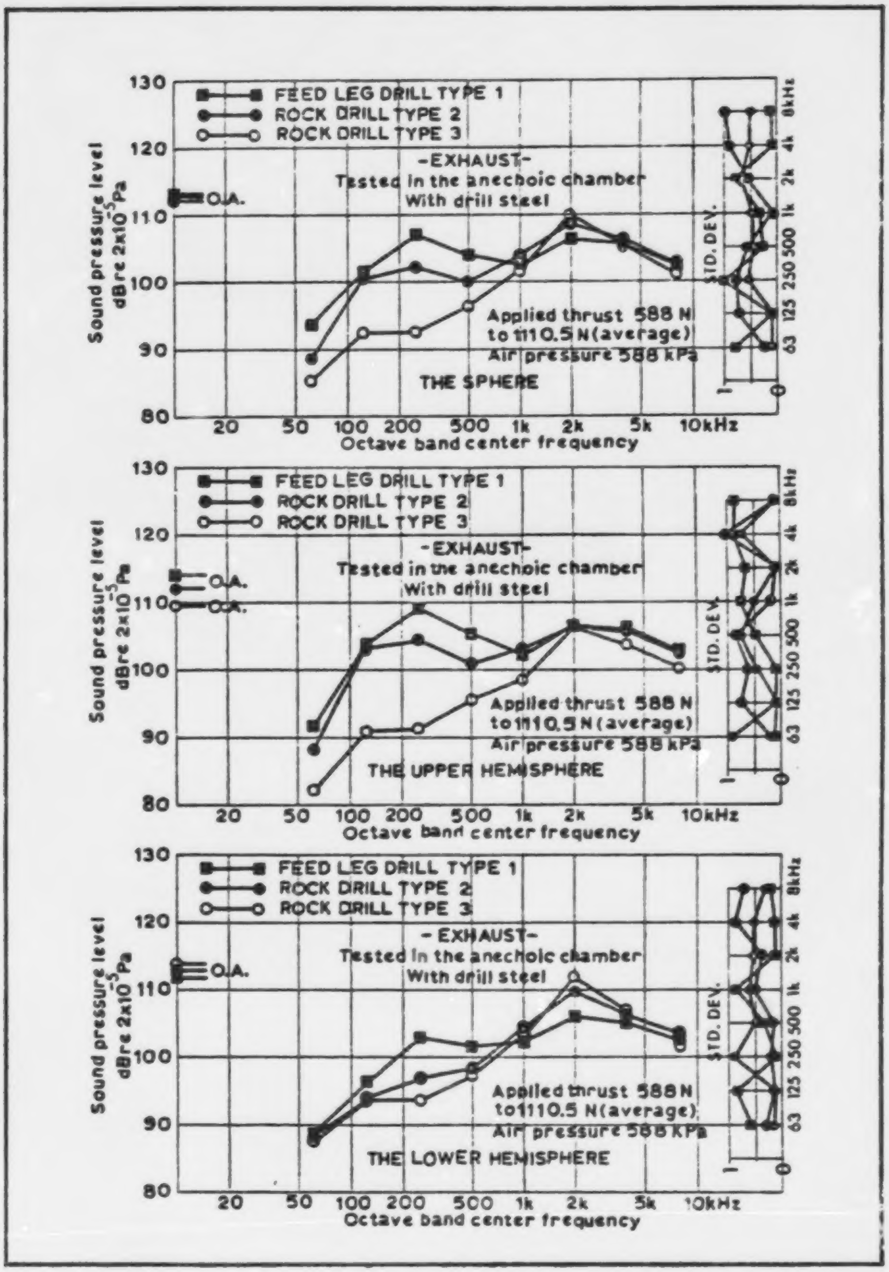


Figure 8: Noise of Rock Drills with Exhaust and Drill Steel.

The sound spectrum (Figure 7) shows that feed leg drill Type 1 causes the most noise. For frequencies of 2000 to 8000 Hz, the results are the same for the Type 1 feed leg drill and the Type 2 rock drill. The field of high frequencies belongs to the impact noise (steel noise). At those frequencies, the muffler reduces the noise to a minimum that is considerably more in the upper hemisphere than in the lower. However, if we compare the values with the exhaust system of the same rock drill, the muffled Type 3 rock drill gives the same results over all frequencies from 1000 Hz to 8000 Hz (Figure 8). In the lower hemisphere, the muffled Type 3 gives poorer results (see O. A. and frequencies on diagrams).

From these spectra, it can be seen that the exhaust system lowers the noise in the rock drills that have no built-in silencer. The Type 3 rock drill, silenced and with exhaust (Figure 8) on the lower hemisphere, gives a high value at 2000 Hz (siren, mouthpiece, which can be explained by the smothering of the air stream). This spectrogram (for the Type 3, silenced and with exhaust, upper hemisphere) is very important for use in the future construction of the ideal integral muffler which will be discussed later.

4.7 The CAGI-PNEUROP Standard for Testing a Feed Leg Machine

The CAGI-PNEUROP test was performed under unfavourable conditions. Granite was selected from glacial gravel around the Institute for Mineral Industry Research at Mont St-Hilaire, and was very friable.

The test environment was not satisfactory. "This method calls for an environment which can be obtained only on an open site above a hard reflecting plane. An example of a suitable test site would be an open space of which the central twenty (20) meters are covered with concrete, asphalt, or similar hard material." (CAGI-PNEUROP Test Code)
For this reason, our measurements have lower values (Figure 9).

The sound spectra of the CAGI tests confirm the values of our measurements performed in the anechoic chamber. The Type 2 silenced rock drill showed greater efficiency at frequencies of 1000 Hz and 2000 Hz. This test shows that the Type 1 feed leg drill has a greater noise level over the whole part of the spectrum (except 125 Hz).

The measurements were repeated several times. The instruments and the microphone tripod were isolated with anti-vibration pads during the measurements.

4.8 Directivity Factor

The noise directivity factor is very important in rock drill operations. The Japanese manufacturers first found a practical solution and lowered a part of the noise by placing the operator in the best position (Figure 2.6). For this purpose diagrams were constructed (Figures 10, 11 and 12) with the calculated minimum and maximum values of the directivity factors for: a) Feed leg drill Type 1, with and without exhaust; b) Rock drill Type 2, with and without exhaust; and c) Rock drill Type 3, with and without exhaust.

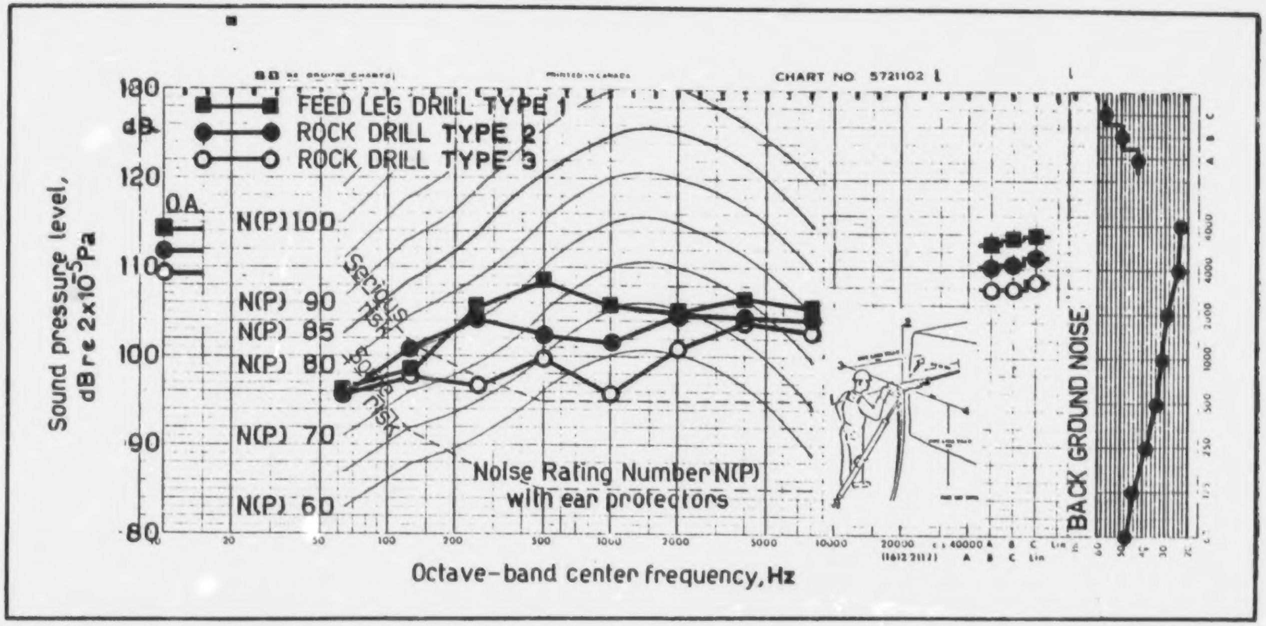


Figure 9: The Noise Spectrum Produced by Rock Drills (CAGI-PNEUROP Test Code).

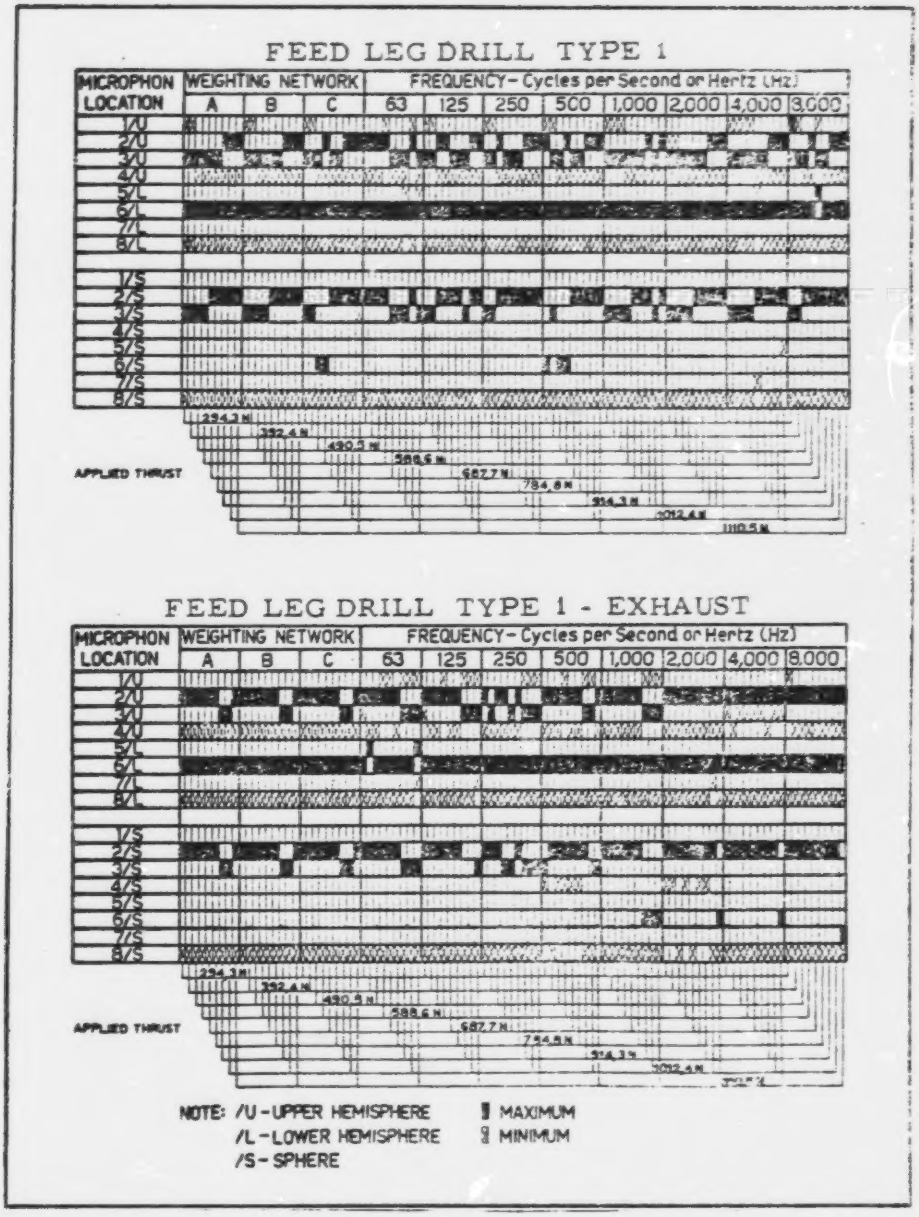


Figure 10: Diagrams of the Directivity Factor for Feed Leg Drill Type 1, without and with Exhaust.

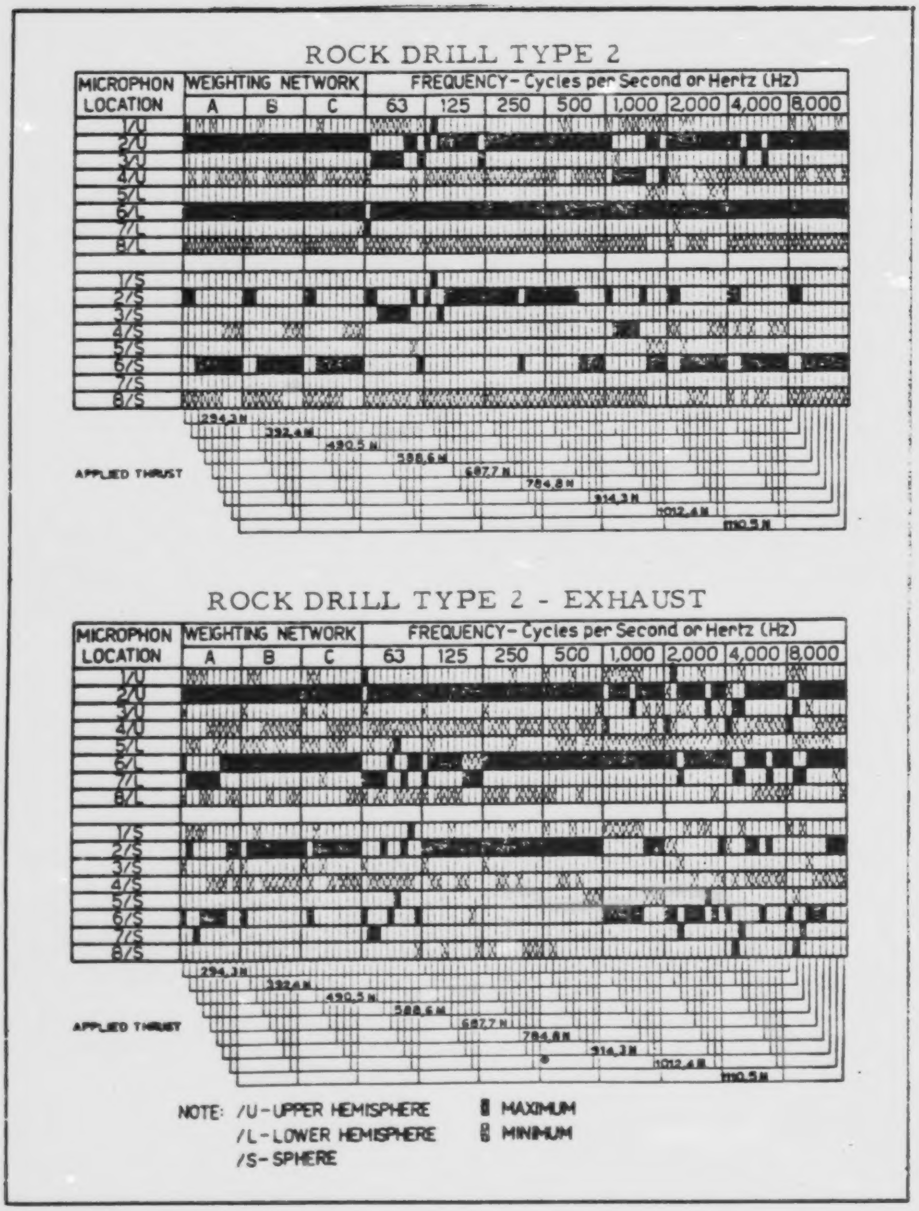
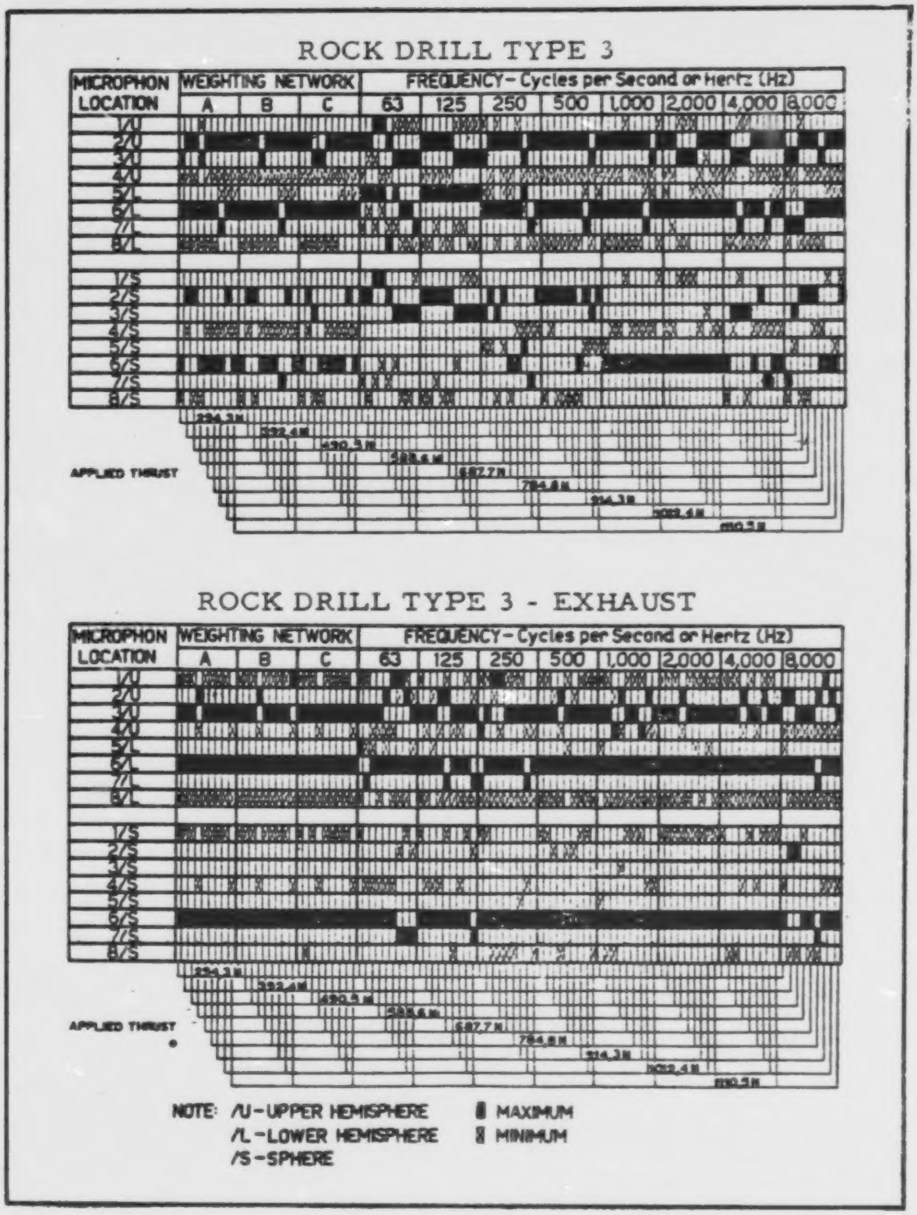


Figure 11: Diagrams of the Directivity Factor for Rock Drill Type 2, without and with Exhaust.


ROCK DRILL TYPE 3

ROCK DRILL TYPE 3 - EXHAUST

Figure 12: Diagrams of the Directivity Factor for Rock Drill Type 3, without and with Exhaust.

Feed leg drill Type 1, with and without exhaust, shows similar values for the maxima and minima of the upper hemisphere, the lower hemisphere and the sphere. In all cases, the right-handed operator suffers less from the noise; this is especially so in the lower hemisphere. The maximum values of the common directivity factor are distributed regularly, as shown in Figure 10.

The Type 2 rock drill, with and without exhaust, shows greater irregularities (Figure 11). The values of the upper and lower hemisphere for the Type 2 without exhaust show very good regularity. The SPL of lower frequencies (63 - 500 Hz) of the sphere is concentrated around microphone location 2, but, at 1000 Hz, there was a turning point effected by displacing the frequencies of 2000 Hz, 4000 Hz and 8000 Hz at microphone location 6. In general, the right-handed operator has the advantage.
In Type 2 with exhaust, a greater dispersion at higher frequencies begins from 1000 Hz. Generally, in the case of the dBA-Network, the right-handed operator is placed in the most favourable position in relation to the sound expansion. The frequencies of 63 Hz, 2000 Hz, 4000 Hz, and 8000 Hz show an irregular sequence in the Type 2 without exhaust. The most dangerous frequencies for the hearing sense (1000 Hz and 2000 Hz) have less influence upon the left-handed operator (Position 1 and 5) than upon the right-handed operator.

The Type 3 rock drill, without exhaust, gives an interesting diagram, where the upper hemisphere and the sphere give the right-handed operator an advantage in relation to the minimum noise, while, in the lower hemisphere, exclusive advantage is given to the left-handed operator (Figure 12). The Type 3 with exhaust changes the picture. The noise in the upper hemisphere and the lower hemisphere give an advantage to the left-handed operator, while the minimum noise in the upper hemisphere belongs to the right-handed operator. After a detailed review of the diagram, we see that the Japanese inventors very simply and excellently resolved a very important problem with a built-in directivity nose (see page 6).

4. 9 The Relation between the Thrust on the Rock Drill and the Noise

The use of the feed leg is necessary for easier work and greater efficiency. For a successful application of the rock drill, a corresponding thrust is necessary, which is always greater than the man thrust reaction (~ 490 N).

The maximum drilling speed in the hammer of 23 kg is reached at 90 to 105 kp thrust on the drill steel (Figure 13). In hand drilling, there is no way to reach a constant thrust which would be greater than 490 N. The diagram shows the importance of the feed leg use for the drilling efficiency because it assures optimal penetration.

The sound-pressure level depends upon the thrust increase and, consequently, upon the penetration increase. This is the most important part of the investigations because the real value of the muffler is found with an increase in penetration rate. Such an investigation has not previously been made.

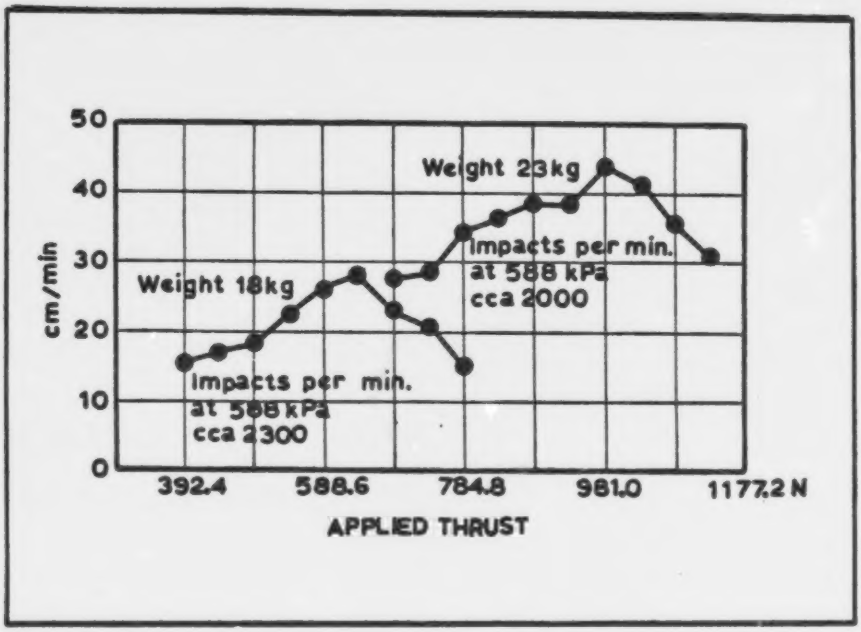


Figure 13: Relation of Thrust on the Drill Steels (N) and Drilling Efficiency (cm/min). (30)

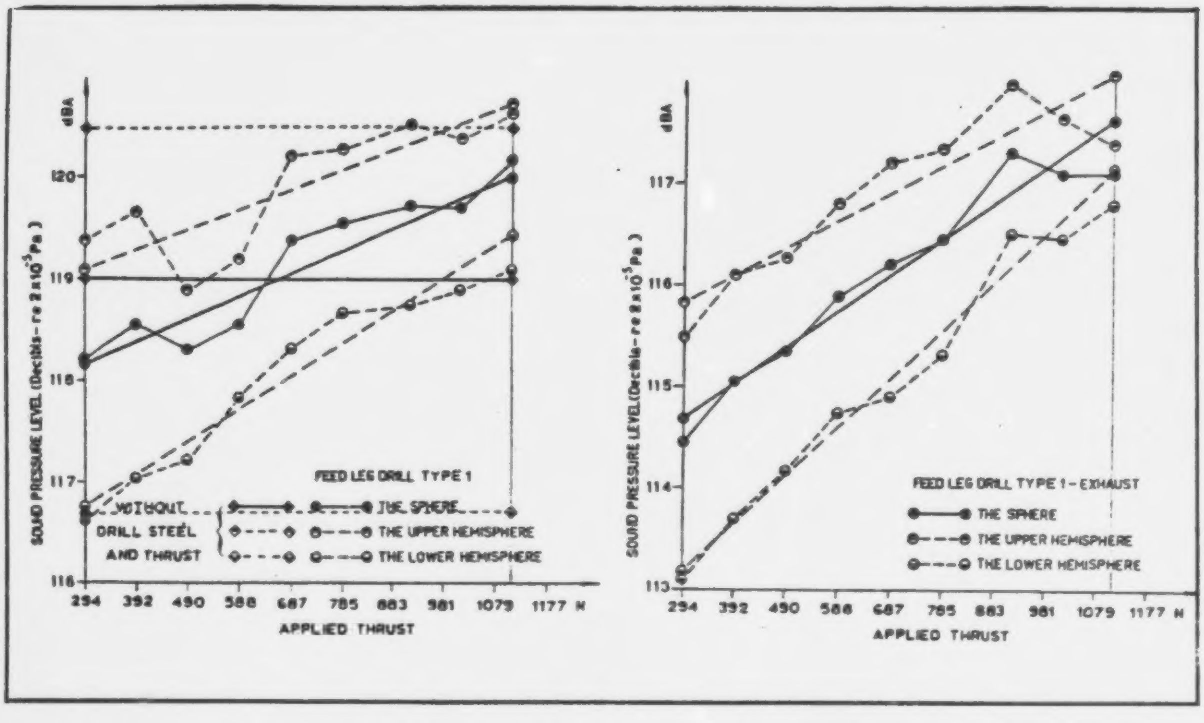


Figure 14: Relation of Thrust on the Feed Leg Drill Type 1 and the Sound Pressure Level (dBA) - without and with Exhaust.

By increasing the thrust on the Type 1 feed leg drill, the SPL is increased faster in the lower hemisphere than in the upper hemisphere (Figure 14). The progressive line - dBA,in the sphere for feed leg drill Type 1 with exhaust (Δ 36°),increases faster than the progressive line in the sphere for the feed leg drill (Δ 24°) without exhaust. For the maximum thrust of 1110N, the difference between non-exhaust and exhaust for feed leg drill Type 1 decreases from 3.5 dBA to 2.5 dBA at a thrust of 294 N.

However, for the Type 2 rock drill (Figure 15), the progressive lines dBA in the sphere for exhaust and non-exhaust systems are almost parallel (Δ 22°, Δ 25.5°), and the difference between minimum and maximum thrust for non-exhaust system is 1.6 dBA and,for the exhaust system, 1.8 dBA. The differences are smaller than for the Type 1 feed leg drill.

For the Type 3 rock drill (Figure 16) those differences are further decreased -- for the exhaust system, 2.5 dBA , and, for the non-exhaust system, 2.9 dBA. In both systems, the noise progression lines are parallel (Δ 32°, Δ 35°).

The differences in SPL (dBA) in each diagram show that the quality of the drill affects the production of noise. They give an exact picture of both hemispheres and offer a theoretical and practical basis for the construction of a new ideal muffler.

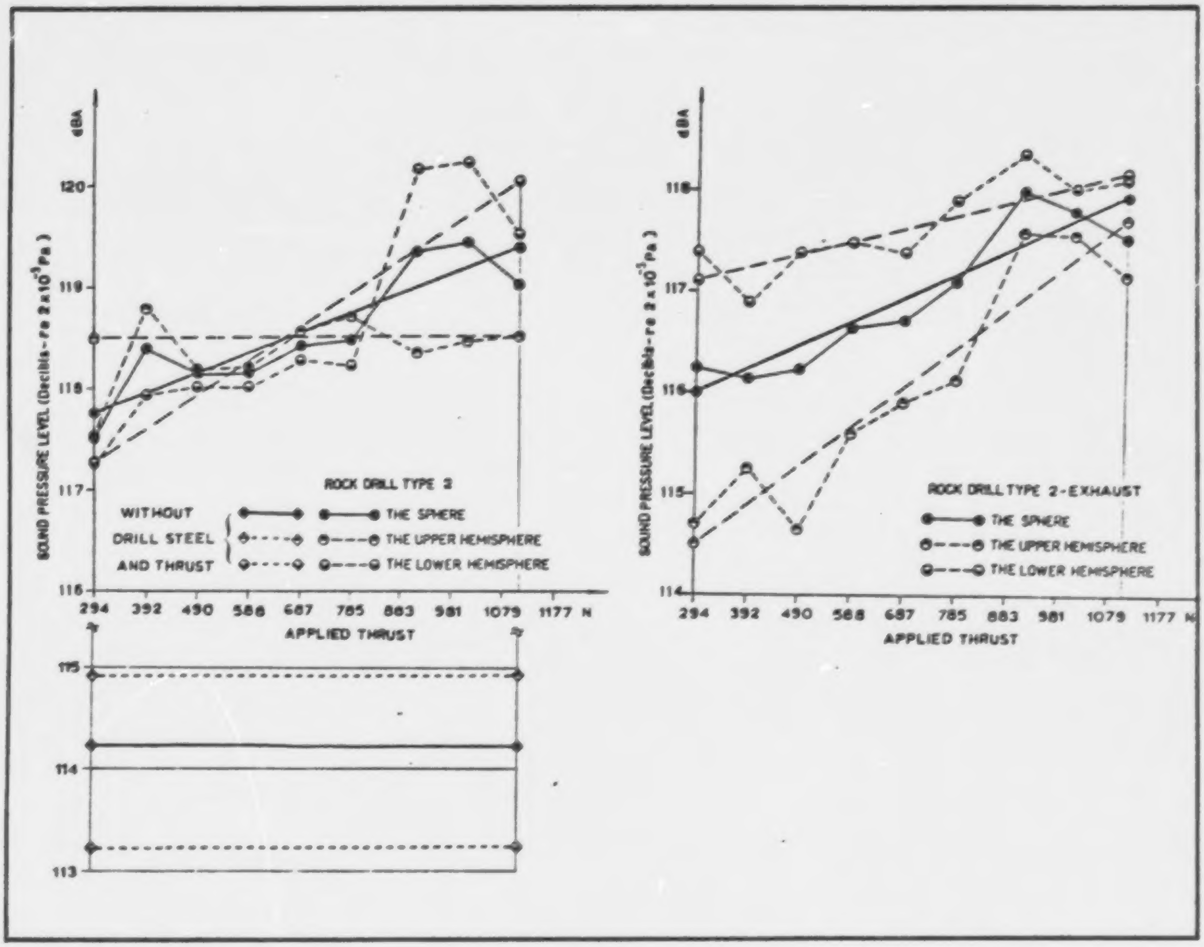


Figure 15: Relation of Thrust on the Rock Drill Type 2 and the Sound Pressure Level (dBA) - with and without Exhaust.

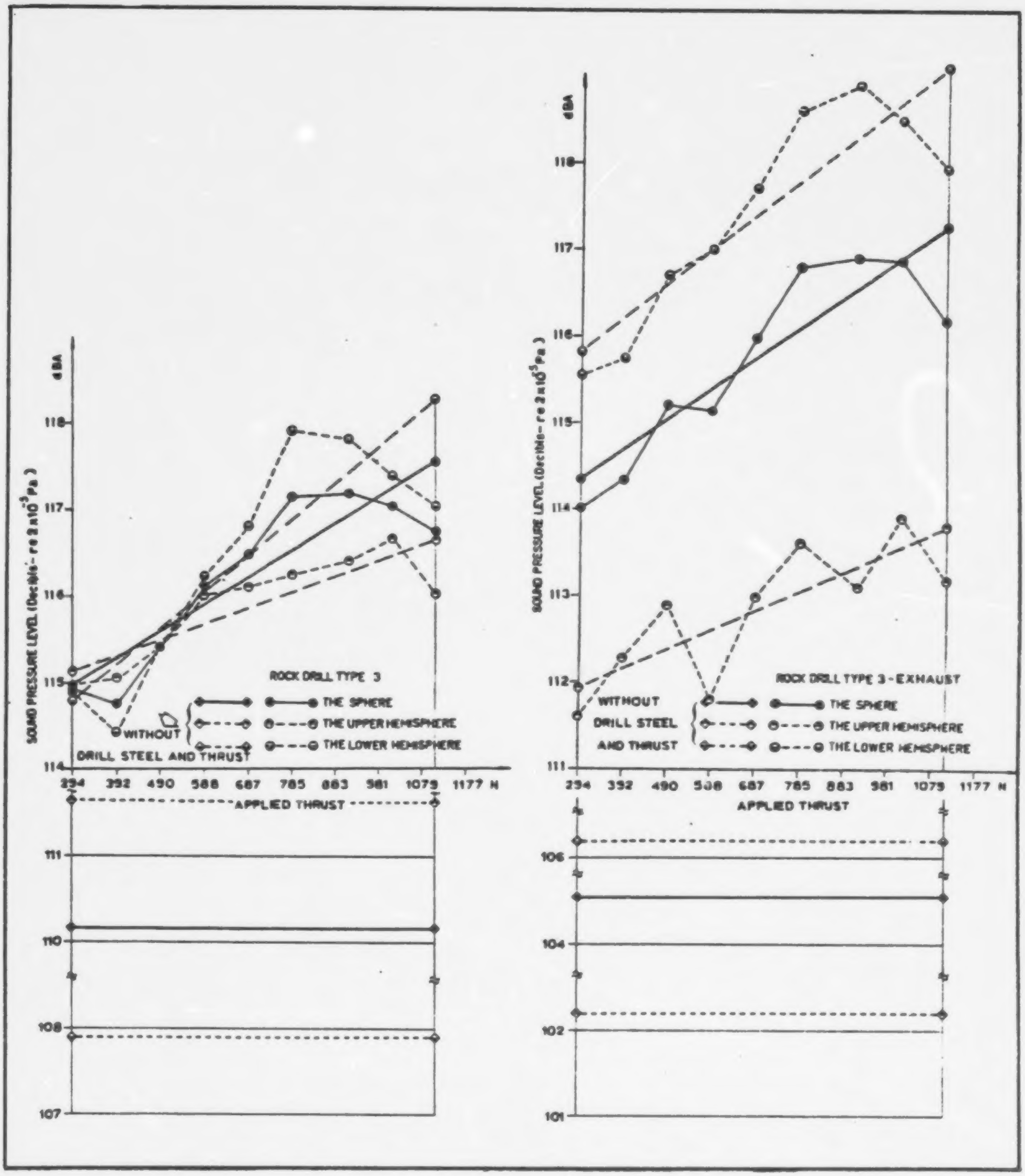


Figure 16: Relation of Thrust on the Rock Drill Type 3 and the Sound Pressure Level (dBA) - with and without Exhaust.

5. NOISE SUPPRESSION OF ROCK DRILLS

An evaluation of the data obtained from the measurements and frequency analyses of the measured sound levels shows the following (Figure 17):

1. The mechanism of noise production is different in every rock drill.
2. Percussion noise corresponds to the number of piston impacts. Spheroidal graphite cast-iron is known to be a noise- and vibration-absorbing alloy and no reason can be found for this anomalous behaviour.

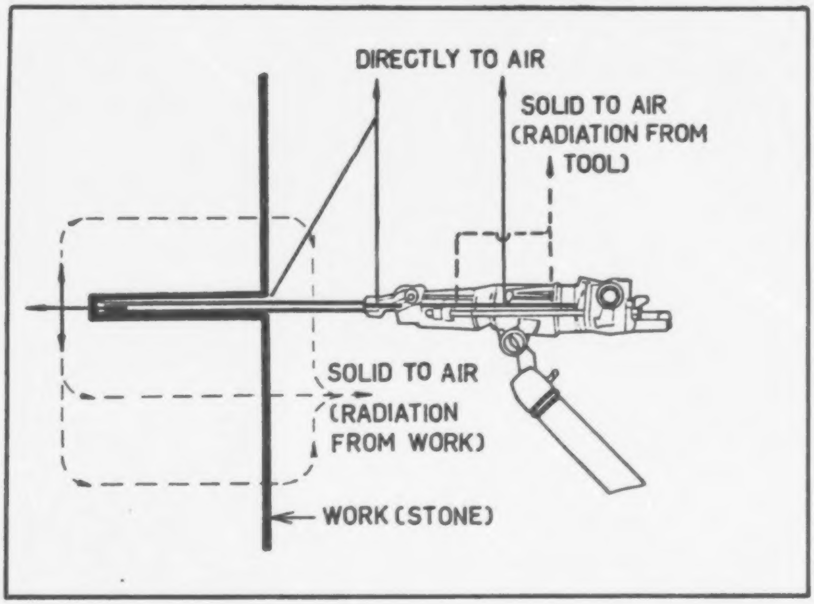

DIRECTLY TO AIR
SOLID TO AIR (RADIATION FROM TOOL)
SOLID TO AIR (RADIATION FROM WORK)
WORK (STONE)

Figure 17: Noise Flow Diagrams from Rock Drill, the Existing Condition.

3. Exhaust noise constitutes approximately 45% of the total noise energy. Noise reduction can be achieved by the addition of an exhaust manifold and a hose to pneumatic hammers.
4. Retainer "ringing" of the drill steel, especially at the beginning of the drilling.
5. Penetration noise or bit noise corresponds to the number of piston impacts and the dimension of the bits. The addition of water to a formerly dry drilling process results in a reduction of approximately 4.5 dB in the bit noise (12).

The measurements show that the sound pressure level of the rock drill noise has been attributed to the following sources:

Feed Leg Drill Type 1

Frequency range Hz	Source	Supporting Data
63 to 250*	Impact between the piston and drill steel, and impact between the drill steel and rock.	Figs. 7, 8, and 9
250 to 2000	Exhausting of air from the exhaust ports.	Figs. 7 and 8
2000 and over	Impact between the piston and drill steel, and impact between the drill steel and rock.	Figs. 7 and 8

* Cut-off frequency.

Rock Drill Type 2 and Type 3

Frequency range Hz	Source	Supporting Data
63 to 125 *	Exhausting of air from the exhaust ports. Impact between the drill steel and rock.	Figs. 7, 8, and 9
125 to 2000	Exhausting of air from the exhaust ports.	Figs. 7 and 8
2000 and over	Impact between the piston and drill steel, impact between the drill steel and rock and resonance of the drill steel.	Figs. 7 and 8

* Cut-off frequency.

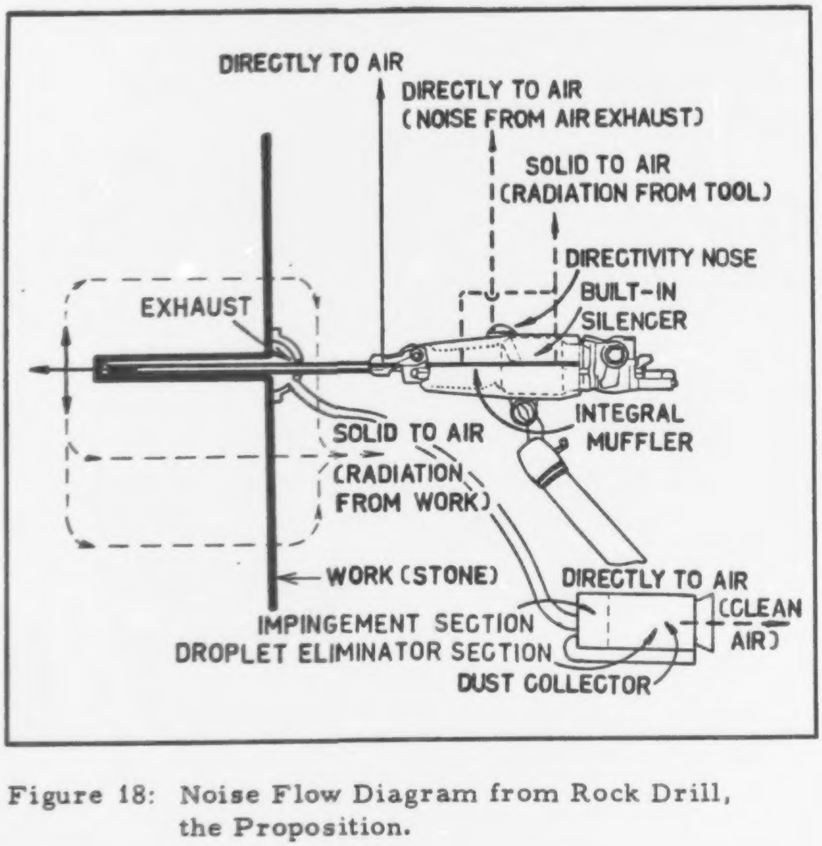

DIRECTLY TO AIR
DIRECTLY TO AIR
(NOISE FROM AIR EXHAUST)
SOLID TO AIR
(RADIATION FROM TOOL)
DIRECTIVITY NOSE
BUILT-IN
SILENCER
EXHAUST
INTEGRAL
MUFFLER
SOLID TO AIR
(RADIATION
FROM WORK)
WORK (STONE)
DIRECTLY TO AIR
(CLEAN
AIR)
IMPINGEMENT SECTION
DROPLET ELIMINATOR SECTION
DUST COLLECTOR

Figure 18: Noise Flow Diagram from Rock Drill, the Proposition.

On the basis of the results presented here the author proposes a possible solution for the problem of abatement of noise from pneumatic rock drills (light and medium) (Figure 18).

The proposition contains the following improvements:

a) Construction of an integral muffler by use of sound-absorbing materials for abatement of noise arising from the impact between the piston and drill steel and the resonance of the drill steel. In the integral muffler, there is a built-in silencer of proven design in which the parts are connected with the "directivity noise". The "directivity factor" has a great influence upon the drill-operator's position. The construction of the drill has to satisfy the following principles:

- the penetration should be the same;
- very little weight should be added with the new design;
- the integral muffler should be functional and an integral part of the machine.

b) The retainer "ringing" of the drill-steel sound level is especially high in the beginning of the drilling cycle. When the drilling begins, the sound factor can normally be neglected. This can be solved technically by an insert of hard rubber in the retainer, but the wearing out of the rubber would be very fast and it would have to be changed often.

c) Construction of an exhaust system from the drill hole for the noise created by the penetration of the drill. The construction must be very simple, easy to handle, and one which permits the whole system to be connected to the dust collector, the efficiency of which depends upon the dimensions. The advantages of this system are many, because the design affords the drill operator protection from the noise and dust. The dust collector should be constructed for the dry drill as well as for the wet drill.

6. CONCLUSIONS

The problem basically remains the same: to give the bit a determined number of strokes in a unit of time. Different designs of rock drills have different numbers of strokes and different piston and hammer weights. For a definite solution of the noise-abatement problem from pneumatic rock drills, the following are proposed:

1. Measurements of the sound-pressure level, the vibration and the penetration of the rock drills which are most used in the world and in Canada and which have shown, until now, the best results in practice. During the tests, the conditions for all the rock drills must be the same. Time did not permit us to consider a new design, in which we would calculate the mechanical characteristics of a new "ideal" rock drill. The new rock drill would show some imperfections that would have to be corrected; this work would be very time consuming.
2. To use the proposed methodology for making the measurements (methodology given in this project).

7. ACKNOWLEDGEMENTS

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ATTÉNUATION DU BRUIT PRODUIT PAR DES PERFORATRICES AU ROCHER

par

M. Savich* et J. Wylie**

RÉSUMÉ

Le code de lutte contre le bruit et la protection de l'ouïe de la province d'Ontario prescrit des niveaux acceptables d'intensité sonore et de temps d'exposition.

En exploitation minière, les opérateurs de perforatrices pneumatiques sont les travailleurs les plus affectés par des niveaux d'intensité sonore élevés. Des ondes sonores d'environ 115 dBA telles que produites par des perforatrices à percussion peuvent causer une surdité temporaire ou permanente. Il est donc de plus en plus nécessaire de mettre au point des méthodes de sondage moins bruyantes.

Les fabricants d'équipement et les chercheurs à l'emploi du gouvernement se sont penchés sur le problème de la réduction du bruit produit par les perforatrices à percussion pneumatiques. C'est ainsi qu'un grand nombre de perforatrices au rocher de poids léger et moyen munies d'amortisseurs de bruit ont été lancées sur le marché. Tous les amortisseurs de bruit commerciaux sont construits pour réduire l'énergie sonore du bruit d'échappement. Des réductions d'environ 5 à 7 dBA ont été obtenues.

De nombreuses nouvelles machines sont actuellement mises au point pour remplacer partiellement ou complètement la perforatrice. Les travaux de recherche sur la réduction du bruit de foration s'amplifient.

Protection de l'environnement : réduction du bruit : perforatrices au rocher : foration : amortisseurs de bruit

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Droits de la Couronne réservés.

NOISE ATTENUATION IN ROCK DRILLS

by

M. Savich* and J. Wylie**

ABSTRACT

Acceptable noise levels and exposure times have been specified by the Noise Control and Hearing Protection Code of the Province of Ontario.

In mining, pneumatic drill operators are the ones most seriously affected by elevated noise levels. Sound waves at about 115 dBA from percussion drills can cause temporary or permanent deafness. There is an increasing demand for quieter drilling methods.

Both equipment manufacturers and government researchers have been investigating the problem of reducing the noise from pneumatic percussion drills. As a result, a large number of light and medium muffled rock drills are on the market. All commercial mufflers are constructed to subtract sound energy from the exhaust noise. Attenuations of approximately 5 to 7 dBA have been achieved.

Environmental Control: Noise Abatement: Rock Drills: Drilling: Mufflers.

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There are a large number of new machines under development which partly or completely replace the rock drill. Research on the abatement of noise associated with drilling is being intensified.

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1. INTRODUCTION

At the present time, the most common method of extraction of ore is the drill/blast system. However, there still exists a need for improved drilling methods and entirely new methods of rock breakage.

The first standard rock drill was made in 1871 and improved in 1914 by the Leyner patent. Since then, many improvements have been introduced (1, 2). Steel centralizers, sliding cones, integral drill steel, automatic feed leg and muffler systems designed to suit the drill characteristics, have made it easier to comply with stricter noise attenuation codes and have improved operator productivity.

Powerful sound waves from percussive rock drills directly striking the ear can cause temporary deafness. If the noise is prolonged, there is a risk that the damage may be so great that the hearing never completely recovers. The ability to hear high-frequency sound is lost first and later, the lower frequencies involving speech are affected and the operator may completely lose his ability to understand the speech of others.

Every problem in noise and vibration control involves three basic elements: a source, a path, and a receiver.

1.1 Noise at the Source

The major noise sources from compressed air operated rock drills are: exhaust noise, impact noise, drill rod noise, and bit noise. About 90 percent of the drill noise is due to the energy released in the exhaust air. This noise is caused by turbulence and pulsations of high pressure air.

1.2 Noise Control in the Path

There are many muffled rock drills on the market with technical data concerning their noise levels. Light and medium rock drills have much lower noise levels because the muffler reduces noise energy by 75% (Figure 1.1(1)).

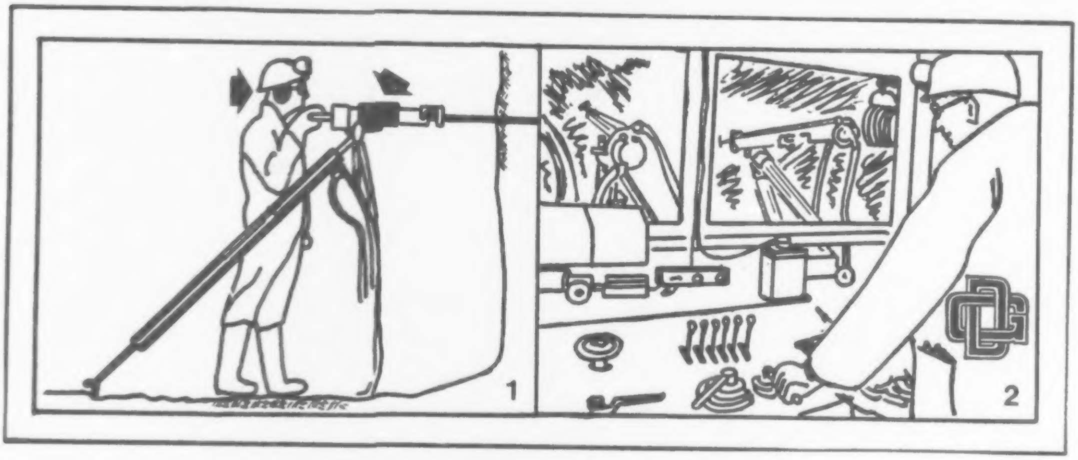

Figure 1.1: Protection against Noise from Rock Drills.
(1) Airleg Drill with Muffler, (2) Jumbo Three-Boom Drill with Cab.

The operator is best protected by an enclosure on jumbo drills (Figure 1.1(2)). Inside the enclosed cab the noise level is 85 dBA, however, the helper is still outside the cab.

1.3 Noise at the Receiver

Neither of the proposed methods permits the miner to work with minimal protection and to communicate freely. The problem still exists, because noise interferes with work, sleep and recreation and some researchers claim it causes strain and fatigue, loss of appetite, indigestion, irritation and headache. High-intensity noise has adverse cumulative effects on the human hearing mechanism, producing temporary or permanent loss of hearing (3).

2. MEASUREMENT OF SOUND LEVELS

2.1 Noise Measurement

Noise level measurements play a basic role in an approach to noise control. The instrument of sound measurement is the sound level meter. The sound level meter consists of a microphone, electronic amplifier, electrical filters, and read-out meter. The sophistication of measurement systems varies from crude, portable, overall sound level meters to elaborate real-time spectrum analyzers. The primary difference between sound level meters is accuracy. Depending on accuracy and function, the ANSI* Standard S1.4-1971, "Sound Level Meter", sets classifications of Types 1, 2 and 3. The U.S. Department of Labor has recommended that Type 1 should be used where precise results are required and Type 2 be used for OSHA** noise criteria requirements.

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* American National Standards Institute.

** The Occupational Safety and Health Act (USA). (Also specified by the Ontario Ministry of Natural Resources.)

Sound level is measured in decibels as sound pressure level (SPL), which represents the mean square pressure on a logarithmic scale.

2.2 Inverse Distance Law and the Effect of the Room Constant, R

A free-sound field is a field in a homogeneous, isotropic medium free from boundaries. In practice, it is a field in which the effects of the boundaries are negligible over the region of interest. In a free field the sound pressure level tends to decrease 6 dB for each doubling of the distance from a source (Figure 2. 1).

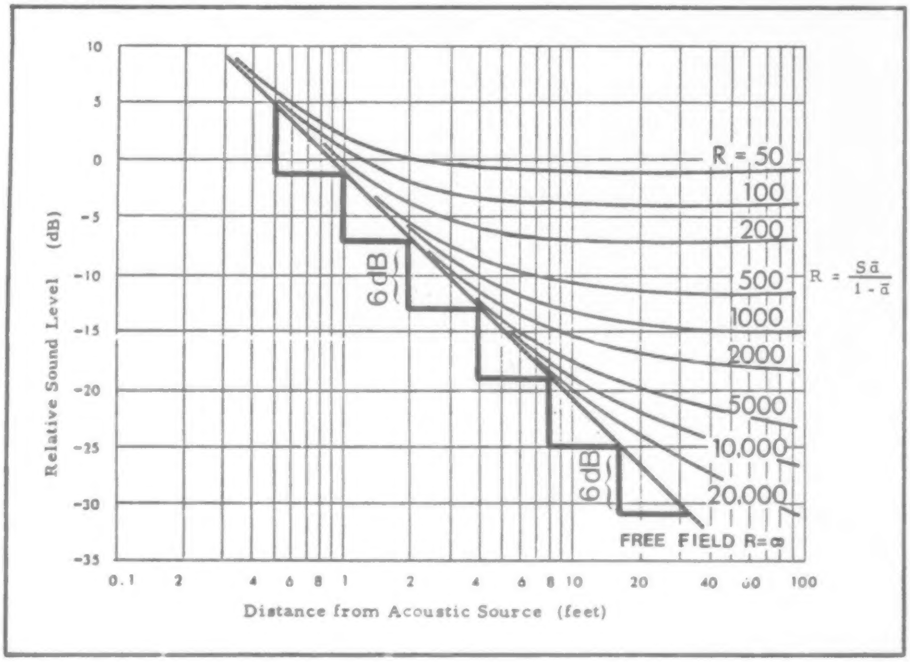


Figure 2. 1: Effect of Distance and Calculating Reverberant Field Decay.

Reverberation is the persistence of sound in an enclosed space, as a result of multiple reflections after the source has stopped emitting. The sound pressure indoors does not decrease by 6 dB for every doubling of distance when measured at a distance far from the source as it does in free-field conditions. The curves in Figure 2. 1 show the attenuation of sound as a function of distance from the sound source for various values of the room constant (R).

The room constant, R, is defined as (4):

$$R = \frac{S\bar{a}}{1-\bar{a}} \qquad \text{(Equation 1)}$$

where: S = total area, in square meters,

$\bar{a}$ = average sound absorption coefficient.

For a complete analysis, a and R must be determined in octave bands. The sound absorption coefficient, a, represents the ratio of the sound absorbed to the sound incident on any material and varies from 0 to 1. The sound absorption coefficient depends on frequency and the thickness of the material. A value of $a = 1$ indicates that all of the acoustic energy is absorbed, and a value of $a = 0$ that all of the acoustic energy is reflected.

The directivity factor (Q) of a transducer used for sound emission is the ratio of the sound pressure squared, at some fixed distance and specified direction, to the mean-square sound pressure at the same distance averaged over all directions from the transducer (Figure 2. 2). The distance must be great enough so that the sound appears to diverge spherically from the effective acoustic center of the source. Unless

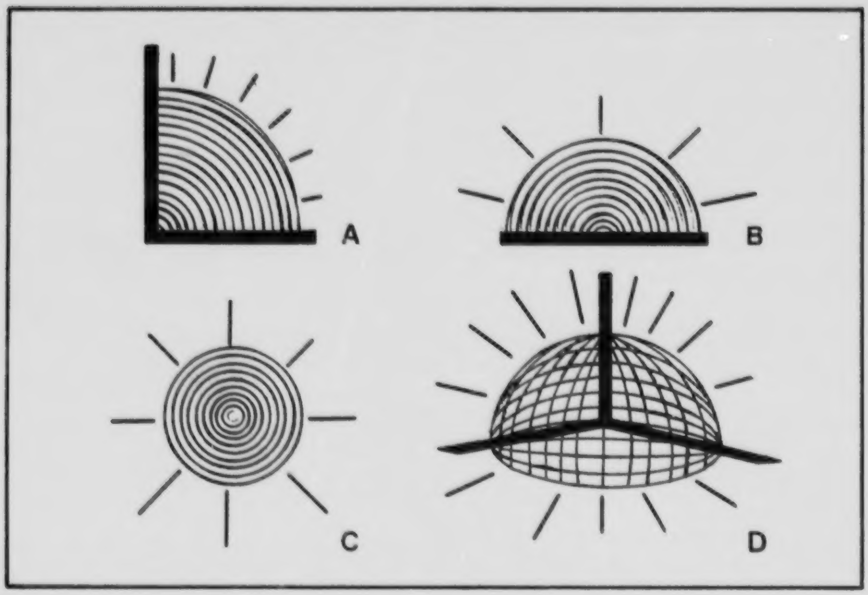


Figure 2.2: Directivity Factor (Q) for Various Sound Radiating Patterns.
A - Radiation over 1/4 of sphere, $Q = 4$,
B - Hemispherical Radiation, $Q = 2$,
C - Spherical Radiation, $Q = 1$,
D - Non-Uniform Radiation, Q depends on direction.

otherwise specified, the reference direction is understood to be that of maximum response.

2.3 Environmental Conditions.

For a better understanding of this phenomenon, the relationship between a free field and a reverberant field, in the relation "miner - rock drill", is shown in Figure 2.3 (5). For indoors free-field conditions, special echo-free rooms are constructed for acoustical investigations and measurements on instruments and machines. Here the absorption coefficient of the walls, α, approaches 1. Extreme reverberant field conditions exist underground when the sound of the source (rock drill) is reflected back and

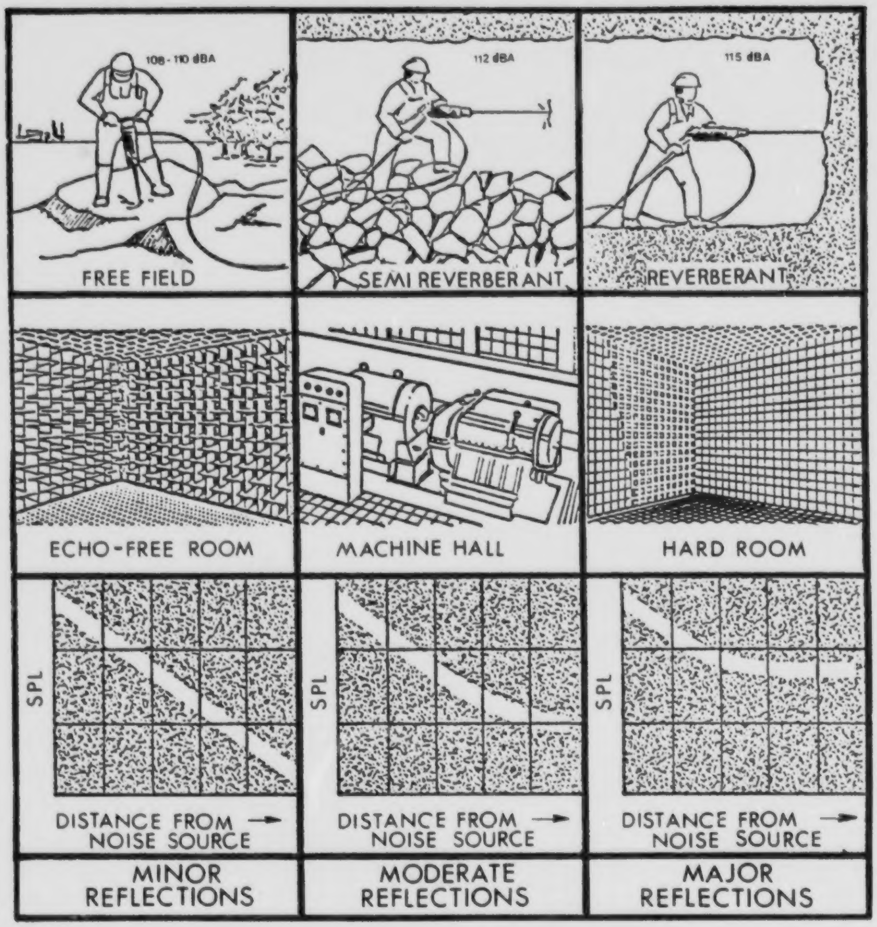

108 - 110 dBA
FREE FIELD
112 dBA
SEMI REVERBERANT
115 dBA
REVERBERANT
ECHO-FREE ROOM
MACHINE HALL
HARD ROOM
SPL
DISTANCE FROM NOISE SOURCE →
SPL
DISTANCE FROM NOISE SOURCE →
SPL
DISTANCE FROM NOISE SOURCE →
MINOR REFLECTIONS
MODERATE REFLECTIONS
MAJOR REFLECTIONS

Figure 2.3: Relationship: Free-Field and Reverberant Field, Outdoors and Indoors (5).

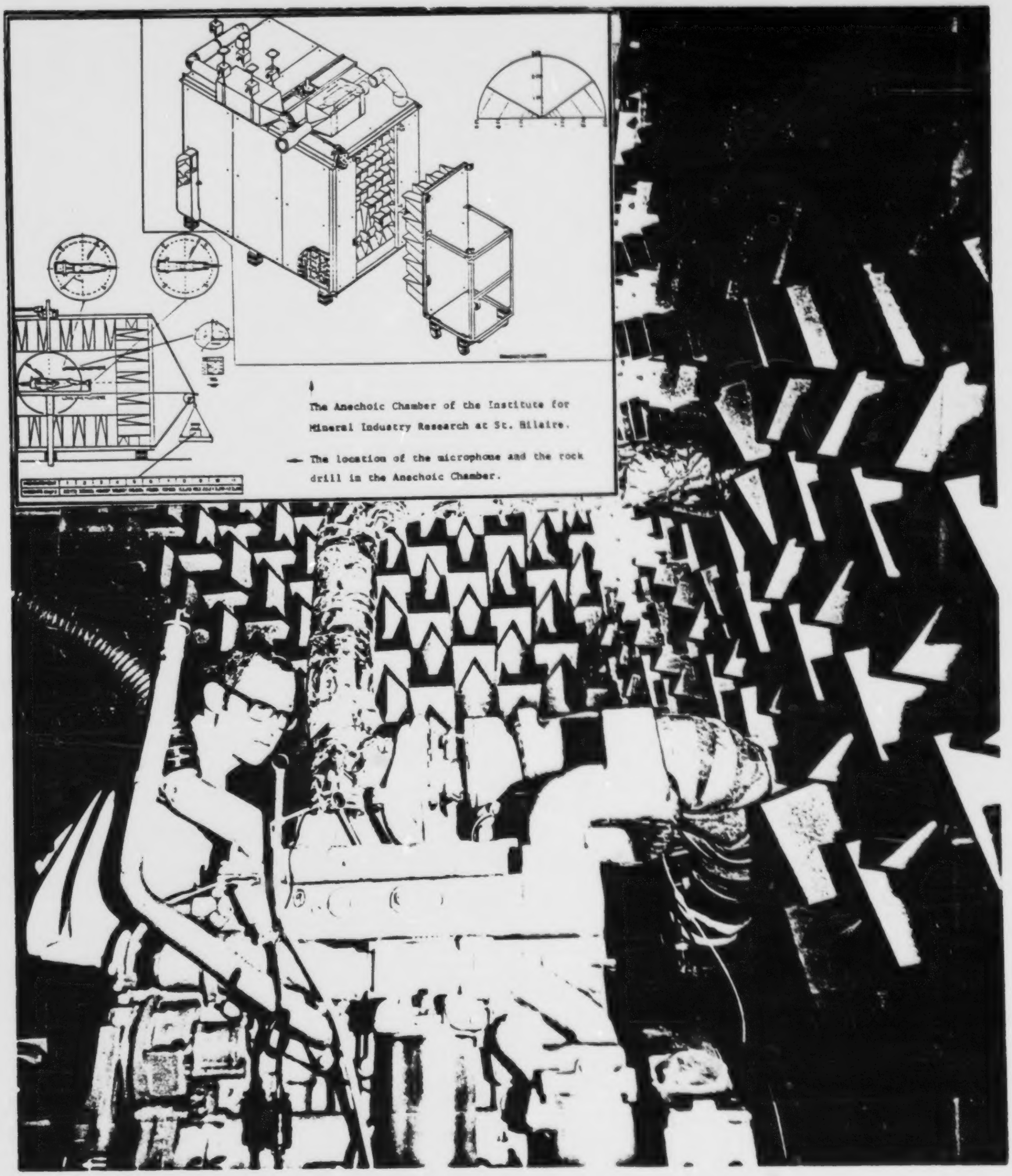
forth between relatively hard surfaces, rather than being absorbed.

The underground reverberant field corresponds to hard rooms, e.g. indoor swimming pools and some hockey arenas, etc. In such buildings, sound absorbers (absorbing panels) are built-in or walls of hollow core masonry blocks, which have slots penetrating into the cores (resonators), are constructed. The series of curves in Figure 2.2 shows the attenuation of sound (SPL) as a function of distance from the sound source for various values of R. The same relation can be seen in Figure 2.3.

One of the greatest difficulties connected with measuring the noise levels of different machines and tools has been that of getting the same measurements made in different laboratories under the same conditions to yield the same results. In this case the acoustically free field should be used. To obtain ideal free-field conditions, sound absorbing rooms have to be constructed; so-called anechoic rooms or chambers (Figure 2.4) (6, 7). The measurements are carried out by determining the sound pressure level at various points over a hypothetical hemisphere surrounding the source of the noise.

2.4 A-Weighting Network

A sound is composed of a number of sound waves of varying frequencies and sound pressure levels. The sum of the sound pressure levels for all the octave bands gives the total sound level. The total sound level tells us nothing about the sound waves of which the noise is composed. Two sound waves with different frequencies may have the same sound pressure, but we do not necessarily hear both. The human ear is most sensitive to frequencies in the range from 2000 to 4000 Hertz (Hz), while much lower frequencies of 50 to 100 Hz are not picked up as well. The noise meter is fitted with a frequency-weighting filter that imitates the ear by attenuating the lower frequencies. There are several weighting networks, but the most widely used is the "A"-weighting network for measuring industrial and traffic noise.



↑ The Anechoic Chamber of the Institute for Mineral Industry Research at St. Hilaire.

← The location of the microphone and the rock drill in the Anechoic Chamber.

Figure 2.4: Caterpillar Semi-Anechoic Cell (bottom) and the Anechoic Chamber at McGill University (top).

2.5 Acceptable Noise Levels

A sound at the threshold of hearing has an intensity of 10^{-12} W/m^2. At a frequency of 1000 Hz, this intensity is equivalent to 2×10^{-5} Pa*. The lower limit of what we can hear is called the threshold of hearing. The threshold of hearing represents the zero on the decibel scale (Figure 2.5). At the threshold of pain, the sound is so loud that it

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* Pa (pascal) = N/m^2.

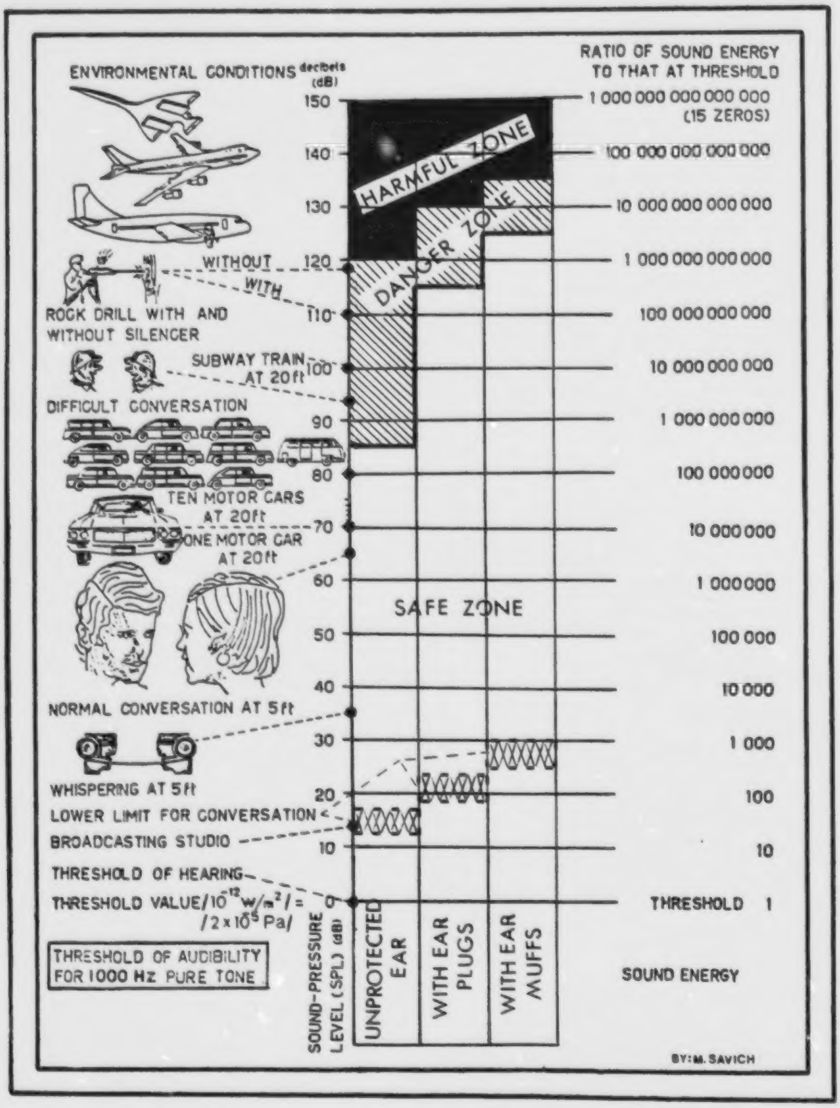


Figure 2.5: Sound Level Scale.

is painful (between 140 and 150 dB). The acceptable noise levels refer to sound pressure levels that represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effects on their ability to hear and understand normal speech.

It has been estimated that over the past 30-year period, the noise levels in mines have risen rapidly. The percentage of this increase is not known because comparative records have not been kept.

Investigations show that the jumbo three-boom drill is one of the noisiest machines (Table 2. 1).

TABLE 2. 1

Sound Pressure Levels at Operator's Ear for Various Rock Drills

Rock Drill	Mean Sound Pressure Level dBA	Sound Pressure Level Range dBA	No. of Measurements
Airleg Drill - Muffled	111. 5 ± 0. 3	96-118	154
Heavy Drifter- Unmuffled	112. 2 ± 0. 2	91-117	194
Jumbo Three-Boom Drill- Unmuffled	116. 3 ± 0. 4	93-120	163

Even with the muffled airleg drill or heavy drifter, earplugs or earmuffs must be worn, because the noise level is still high.

The acceptable sound level should be determined by a sound level meter meeting the Province of Ontario Noise Control and Hearing Protection Code (Table 2. 2), and operating on the A-weighting network using a sound level meter with slow response. An additional requirement

TABLE 2.2

Permissible Noise Exposures

Duration per Day Hours	Sound Level dBA
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
3/4	107
1/2	110
1/4	115-C *

* Ceiling Value.

of the noise criteria for mines is that the miner should not be exposed to sound levels greater than 115 dBA for any period of time without ear protection.

3. MUFFLERS

Over the past twenty years several research projects in Canada have been underway to abate noise from rock drills (9 to 16).

3.1 Classification of Rock Drills

There are three mechanical methods for drilling rock: (1) percussion, (2) rotary, and (3) combined rotary-percussion (1). A percussion drill applies a force perpendicular to the rock surface and the bit moves into the rock making the hole. A rotary drill applies a torsional force as well as thrust to the bit, breaking the rock ahead of it. A rotary-percussive drill uses a combination of both a rotary force and a percussive force applied to the bit. The commonly used mechanical drills may be classified as:

(1) percussion (hammer, piston)

(2) rotary (drag, diamond)

(3) rotary - percussion (roller).

3.2 Percussion Rock Drills

In the percussion rock drill, the piston or hammer reciprocates in a cylinder and strikes the drill steel, anvil block, or tappet on its forward stroke. There are two principles in the operation of the percussion rock drill:

- the piston reciprocates in the cylinder, and
- the drill steel and bit rotate.

The piston movement is effected by a self-acting valve that admits compressed air to one end and then to the other end of the cylinder, with variations on this principle. The drill steel rotation is accomplished by two methods: rifle bar rotation or independent rotation. Most rock drills use the rifle-bar rotation principle (Figure 3.1) (8). Rock drills are generally classified by weight in the following categories (Figure 3.2):

(1) common rock drill: light, medium, and heavy weights;

(2) down-the-hole: all weights.

Most rock drills deliver up to 2000 strokes per minute to the drill steel, and the chuck may rotate at up to 150 rpm. The automatic valve used in percussion drills is the double-kicker port valve and it operates, with variations, on a differential air-pressure principle (Figure 3.1).

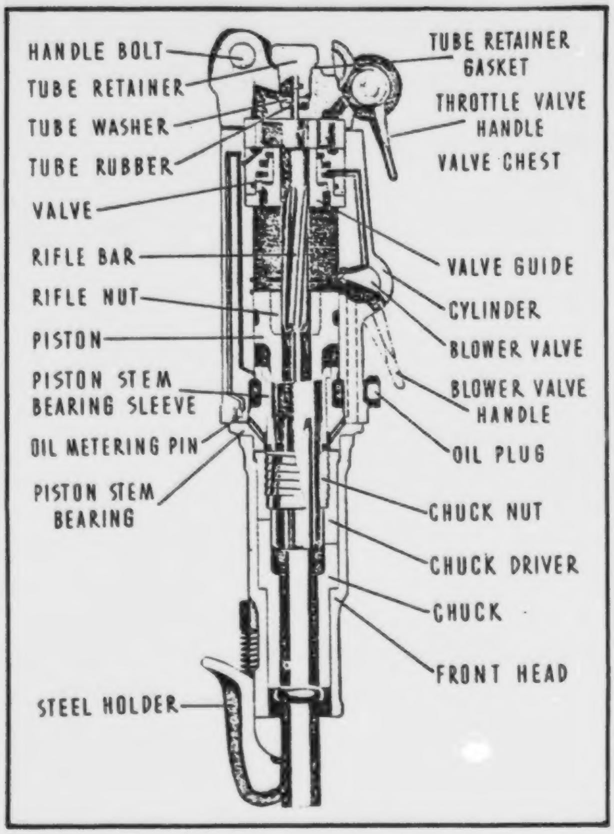
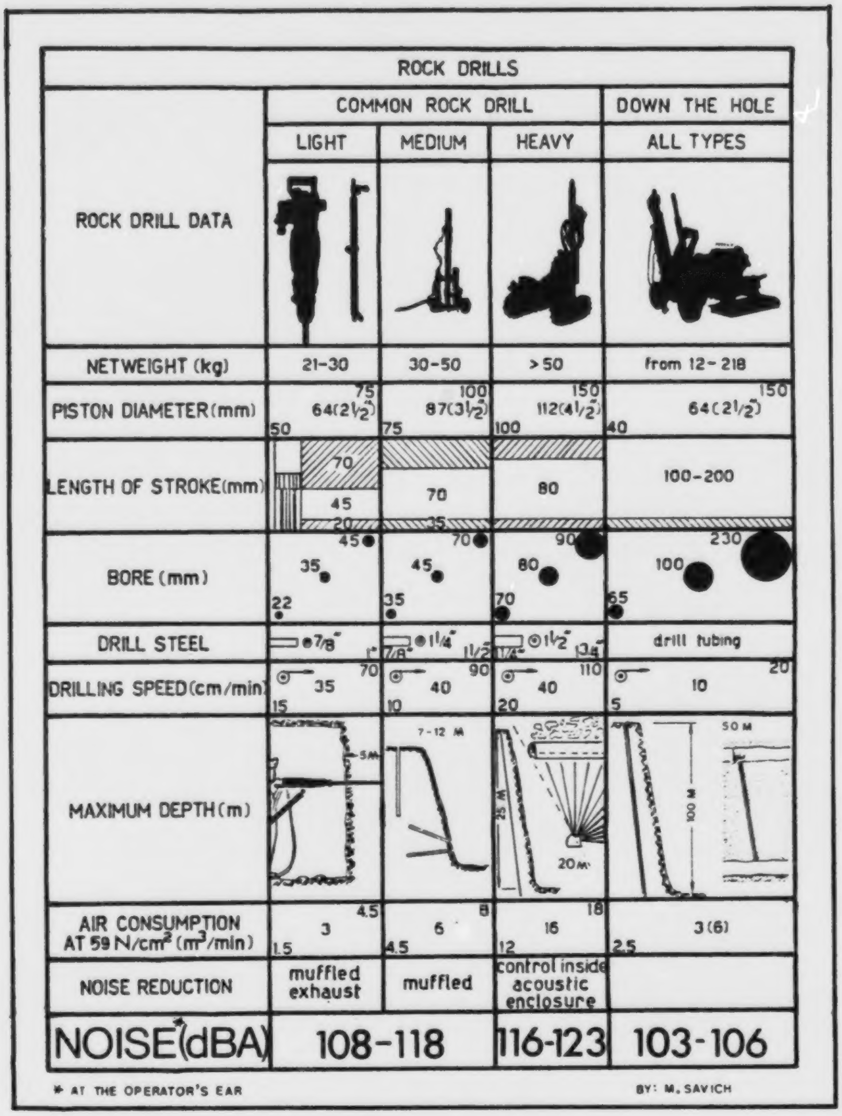

HANDLE BOLT
TUBE RETAINER
TUBE WASHER
TUBE RUBBER
VALVE
RIFLE BAR
RIFLE NUT
PISTON
PISTON STEM BEARING SLEEVE
OIL METERING PIN
PISTON STEM BEARING
STEEL HOLDER
TUBE RETAINER GASKET
THROTTLE VALVE HANDLE
VALVE CHEST
VALVE GUIDE
CYLINDER
BLOWER VALVE
BLOWER VALVE HANDLE
OIL PLUG
CHUCK NUT
CHUCK DRIVER
CHUCK
FRONT HEAD

Figure 3. 1: Percussion Rock Drill.

The down-hole drill, externally rotated, is constructed so that the piston strikes directly on the bit. The rate of penetration is higher than in any other type of percussion drill. The power source for most percussion drills is compressed air.

The noise in mines is mostly associated with rock drills and creates a potentially hazardous acoustical environment. The worst offenders, the rock drills, have been improved by the successful application of devices such as lead-off hoses on the exhaust and mufflers, the development of which has been the result of long and careful research programs (9).



ROCK DRILLS				
	COMMON ROCK DRILL			DOWN THE HOLE
	LIGHT	MEDIUM	HEAVY	ALL TYPES
ROCK DRILL DATA				
NETWEIGHT (kg)	21-30	30-50	> 50	from 12 - 218
PISTON DIAMETER (mm)	75 64(2½") 50	100 87(3½") 75	150 112(4½") 100	150 64(2½") 40
LENGTH OF STROKE (mm)	70 45 20	70 35	80	100-200
BORE (mm)	45 35 22	70 45 35	90 80 70	230 100 65
DRILL STEEL	7/8" 1"	1¼" 7/8" 1½"	1½" 1¼" 1¾"	drill tubing
DRILLING SPEED (cm/min)	70 35 15	90 40 10	110 40 20	20 10 5
MAXIMUM DEPTH (m)	5M	7-12 M	25 M 20 M	100 M 50 M
AIR CONSUMPTION AT 59 N/cm² (m³/min)	4.5 3 1.5	8 6 4.5	18 16 12	3 (6) 2.5
NOISE REDUCTION	muffled exhaust	muffled	control inside acoustic enclosure	
NOISE* (dBA)	108-118		116-123	103-106

* AT THE OPERATOR'S EAR

BY: M. SAVICH

Figure 3.2: Classification of Rock Drills.

3.3 The Muffler Design Criteria

The muffler designed for any application should satisfy five criteria simultaneously (17):

(1) the acoustical criterion which specifies the maximum noise allowed;

(2) the aerodynamic criterion which specifies the maximum acceptable average pressure drop;

(3) the geometrical criterion which specifies the maximum allowable volume and the restriction on shape;

(4) the mechanical criterion which specifies the material of the rock drill; and

(5) the economic criterion which specifies inexpensive techniques and operating costs equal or similar to unmuffled machines.

The foregoing criteria do not make the rock drill mufflers impractical, but they do limit the use of muffling techniques which are used in other industrial fields.

With regard to provincial noise control recommendations, no noise standards exist for mining equipment such as rock drills -- only for the cumulative exposure factor of personnel. For designers and producers of rock drills a confusing situation results as to what is the maximum allowable noise level of rock drills. If we set forth the acoustical criterion which specifies 90 dBA as the upper limit of noise exposure in accordance with the CAGI*-PNEUROP** Test Code, we must consider silencing techniques that meet other criteria such as aerodynamic pressure losses, size, weight, materials and cost. The best way to reduce noise from rock drills is through engineering control or design of the noise source. This may be accomplished by the equipment manufacturers or the users.

---

* Compressed Air and Gas Institute (USA).

** European Committee of Manufacturers of Compressed Air Equipment.

There is no real or technical distinction between a muffler or silencer; one manufacturer may call the device a silencer and another may call the same device a muffler. These devices can be divided into two basic groups: absorptive and reactive. Absorptive mufflers contain fibrous or porous materials and depend on their absorptive properties to reduce noise. Reactive mufflers depend on the reflection or expansion of the sound waves with corresponding self-destruction as the basic noise reduction mechanism. In the practical application of muffling systems to rock drills, one of four techniques, or some combination of the four, can be used:

(1) positioning of the exhaust pipe away from the operator's exposure area;

(2) use of construction materials having sound-absorbing qualities;

(3) use of an expansion chamber or a resonating chamber, which can be used as an acoustical filter;

(4) use of diffusion to break up the sound wave at the exhaust exit.

3.4 Acoustical Performance of Reactive Mufflers

The performance of a reactive muffler is determined by one or more resonators, chambers, or finite sections of pipe. The simplest form of reactive muffler is the single expansion chamber (Figure 3.3) (17).

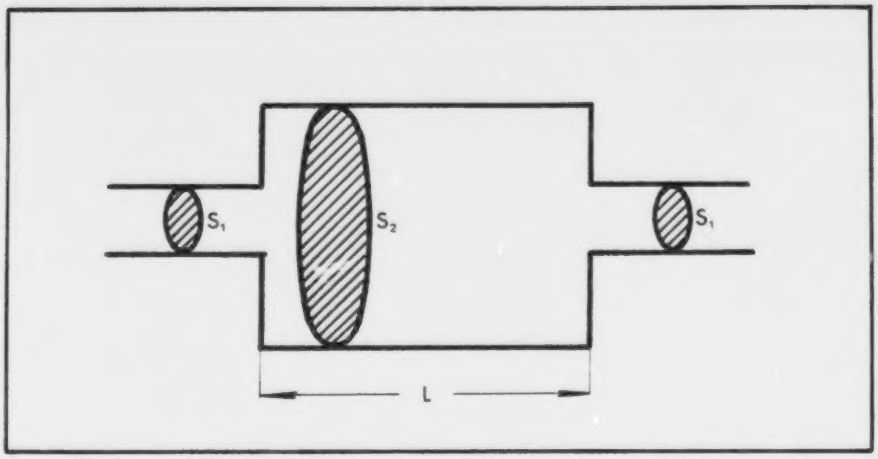


Figure 3. 3: Simple Expansion Chamber

By considering the reflection and expansion of sound waves as they flow through pipes and chamber, the ratio of the sound power incident on the muffler to the sound power transmitted by the muffler, the Transmission Loss (TL), can be calculated:

$$TL = 10 \log [1 + 1/4 (m - \frac{1}{m})^2 \sin^2 kL] \text{ dB}$$

where: $m = \frac{\text{muffler cross-sectional area}}{\text{duct cross-sectional area}} = \frac{S_2}{S_1}$

$k = \frac{2\pi}{\lambda}$

λ = wavelength of sound

L = muffler length (metres).

The magnitude of the transmission loss depends on the value of m and on frequency as in the sine function (kL) (Figure 3. 4). The peak attenuation occurs at frequencies which correspond to the relations, $L = \lambda/4$, $3\lambda/4$, $5\lambda/4$, $\cdots$. Because of this $\lambda/4$ relationship, these mufflers are called "quarter wave mufflers".

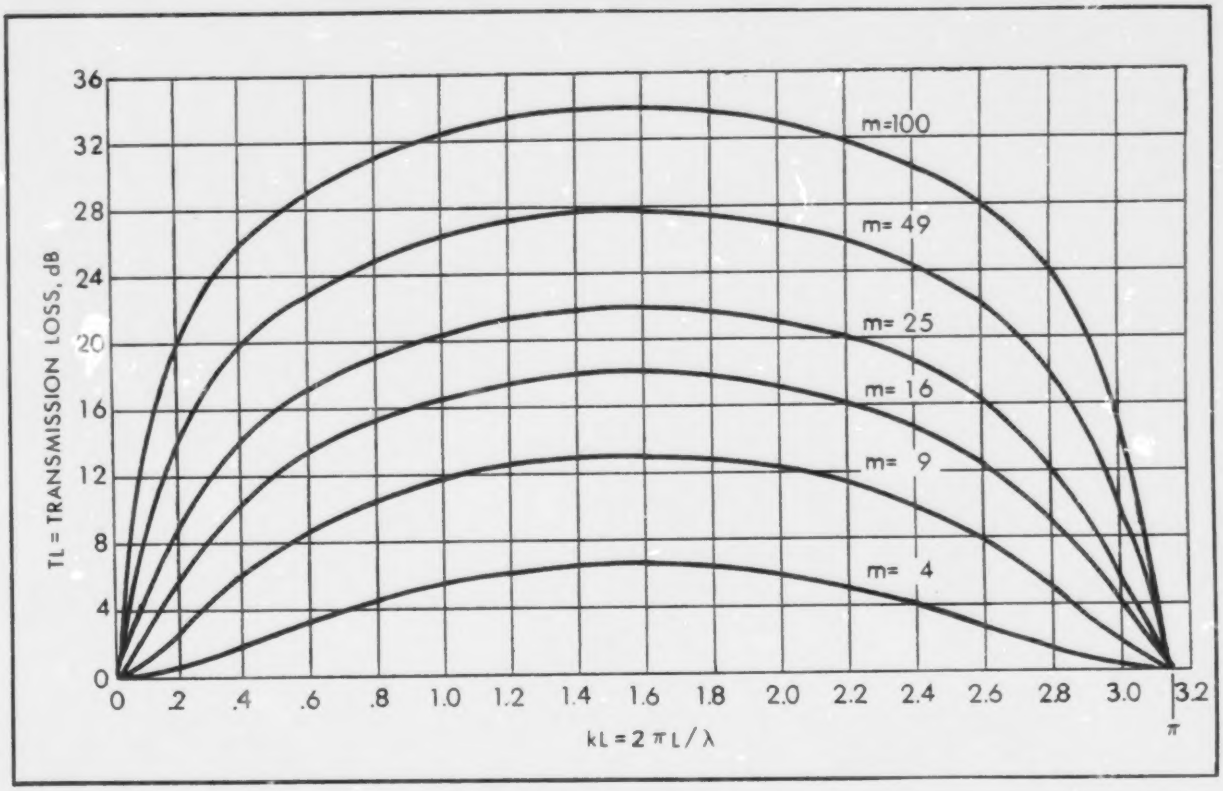


Figure 3.4: Transmission Loss (TL) Curves for Reactive Mufflers (17).

In the same way, the attenuation vanishes at frequencies which correspond to the relations, $L = \lambda/2, \lambda, 3\lambda/2, \cdots$.

When designing the reactive muffler, there are three main factors to consider:

(1) The larger the cross-section of the expansion chamber, the greater the attenuation and reflection and the greater the potential muffling.

(2) The natural frequency of the chamber is important and is largely dependent upon its length.

(3) The natural frequency of the tailpipe is dependent upon its diameter and length.

There are two more factors which can affect predictions and these can be very difficult to calculate, namely, the source impedance and the terminal impedance.

Commercial designs are mostly developed empirically and generally call for specific lengths of pipes before and after the muffler in order to minimize loss of machine power and to maximize the sound energy loss.

3.5 Acoustical Performance of Absorptive Mufflers

Absorptive mufflers are used in applications where a narrow-band noise predominates, but the frequency varies because of a wide range of operating speeds.

The acoustic performance depends upon the dimensions, internal arrangement, and kind of absorptive material used. It is extremely important to correlate the acoustic performance with the flow rate through the muffler.

Absorptive mufflers incorporating parallel baffles are available commercially in modular units. In order to meet this modular concept, the units can be assembled together, to fit duct sizes or attenuation requirements. Parallel baffles are usually applied to noise control of equipment such as centrifugal compressors, fans, jet engines, and gas turbines.

3.6 Present Status of Engineering Control of Noise Produced by Rock Drills

A systematic study of noise abatement of rock drills begins with an evaluation of the insertion loss (IL), the difference between two sound pressure levels which are measured at the same point in space before and after a muffler has been inserted. A pneumatic percussion rock drill transmits noise to the air simultaneously from four principal noise sources:

(1) exhaust noise,

(2) impact or percussion noise,

(3) drill rod noise, and

(4) bit or penetration noise.

The sound energy from each part must be determined and abated in order to find the best practical technical solution to reach the desired noise attenuation.

3.6.1 Manufacturers of rock drills

A large number of light and medium muffled rock drills are on the market, and some technical data are available concerning their noise levels, details of construction and the factors that influenced their design (Table 3.1) (18 to 23). All commercial mufflers are constructed to subtract sound energy from the exhaust noise. The noise spectra of two rock drills of approximately the same quality were compared in muffled and unmuffled versions, as shown in Figure 3.5 (18, 21), which includes noise rating curves. These curves are intended for use when the machine operator wears ear protectors having the attenuation characteristics shown in the inset graph.

Atlas Copco drills have, on the average, a lower noise output than Ingersoll-Rand drills. The low-frequency noise level of the Ingersoll-Rand drill is low, however, and this is why its noise spectrum matches the noise

TABLE 3.1

The Main Types of Mufflers on Light and Medium Rock Drills in Canadian Mines

Type and Manufacture	Weight (kg)	Piston Diameter (mm)	Length of Stroke (mm)	Impact/min at 588 kPa (85 psi)	Type of Muffler	Attenu-ation dBA
BBC 25W Atlas Copco	29.7	70	70	2,050	Diffusion cylinder and reactive chamber	5-6
S 63 FM Gardner-Denver	36.2	51.5	--	1,980	Reactive chamber and diffusion exit	6
303A Holman			50.8	2,600	Durable synthetic material	5
JR 300M Ingersoll-Rand	33.5	76.2	51.4	2,200	Reactive chamber	6-7
Al 60 M Joy	32.5	79	60	2,400	Reactive chamber	6-7
S-240 M Zimco and U and N	--	--	--	--	Reactive chamber	No data

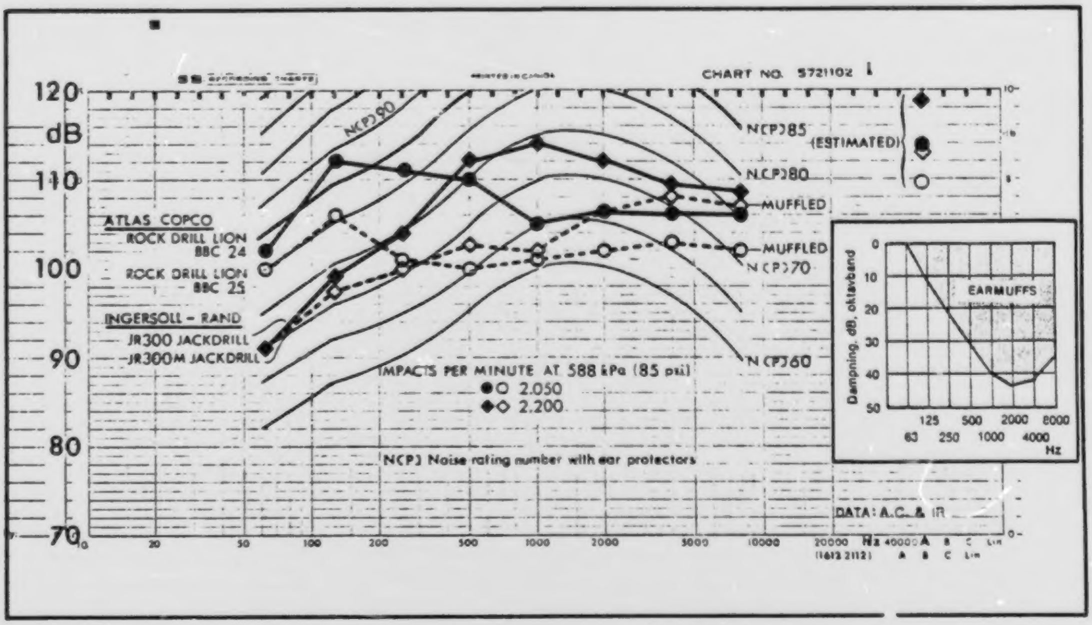


Figure 3.5: The Noise Spectrum Produced by Rock Drills from Atlas Copco and Ingersoll-Rand (the CAGI-PNEUROP Test Code).

rating curves with ear protectors more closely. Because every hammer drill has a different noise spectrum curve, each must have different treatment with regard to attenuation of noise.

The investigations showed that rock drill noise is primarily generated as follows (16):

- at frequencies below 125 Hz, by the impact between the piston and drill steel;
- at frequencies between 125 and 2000 Hz, by the expulsion of air from the exhaust ports; and
- at frequencies above 2000 Hz, by the impact between the piston and drill steel, and between the drill steel and rock.

A practical aspect of the rock drill made by Toyo Kogyo Company is that the directivity factor is determined by the position of the exhaust outlet. At the miner's position, the noise can be 3 to 4 dB less with Toyo Kogyo's exhaust outlet.

On the basis of J. W. Reynolds' research, A. C. Rubber Mfg. Co. Ltd., Vancouver, launched on the market Elastomuffle pneumatic tool mufflers (Figure 3.6) which reduce exhaust sound level up to 6 dBA (24).

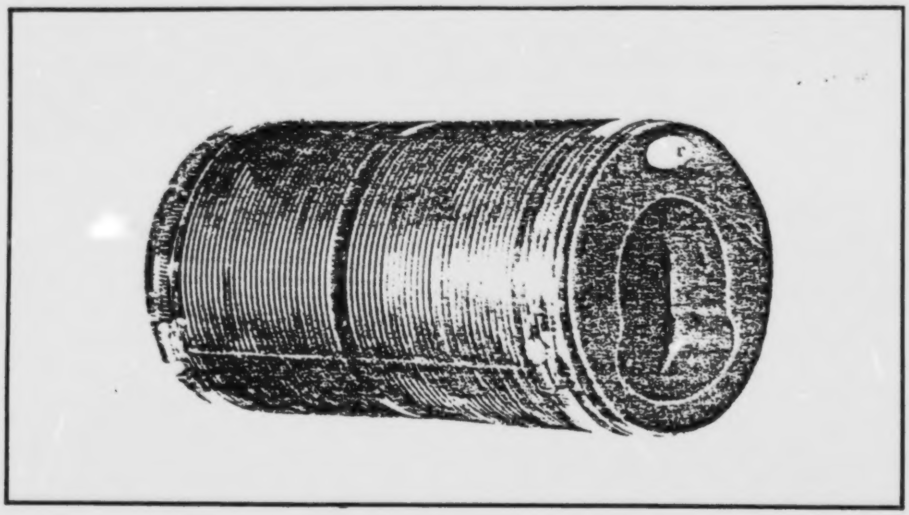


Figure 3.6: Elastomuffle Pneumatic Tool Mufflers, from A. C. Rubber Mfg. Co. Ltd., Vancouver.

The problems with the detachable elastomuffles are as follows:

(1) They were tested on standard cylinders but restrictions such as side rods, cylinder design and the size and shape of cylinder exhaust ports prevented adequate exhaust escape, resulting in freezing or "icing".

(2) Detachable mufflers were frequently removed from the drills and lost by drillers underground.

(3) There were no reliable means of fastening mufflers to the drill cylinders. Metal straps, clamps and bolts failed due to drill vibration and in normal handling underground.

A rubber sleeve-type muffler has been marketed by the Dominion Rubber Company for JR-38 and JR-300 airleg drills. In tests they functioned satisfactorily for noise attenuation and penetration rates but were not acceptable for the following reasons:

(1) too bulky and heavy,

(2) difficult to hold for collaring, especially if coated with exhaust oil;

(3) vulnerable to damage by cutting and puncturing; and

(4) difficult to install and to make drill repairs.

In heavy rock drills, the noise abatement was accomplished by:

(1) corrugated noise suppression exhaust hoses,

(2) cabs with sound suppression,

(3) modification of the drilling method.

An attenuation of about 7 dBA can be reached with an exhaust manifold and a 20-ft length of noise-suppression hose on heavy drifters and jumbo drills, but it is very impractical in mobile equipment.

In order to reduce the noise level at the operator's station, a sound-suppression and vibration-damped cab was constructed for jumbo drill machines. The sheet-steel cab has two sliding doors, safety glass windows and a padded operator's seat. Inside the cab the noise level is below 85 dBA. The cab also has filtered ventilation and lighting (18, 19).

In open pit operations where the strictest of noise limits must be maintained in urban or residential areas, the heavy drill can be supplied with an acoustically treated sound-absorbing steel enclosure around the drill tower. This muffled tower reduces drill noise level to 85 dBA at 7 meters (21).

Today, hydraulic drills are more and more in use on jumbo machines replacing the heavy pneumatic rock drills. Hundreds of the all-hydraulic drills have been sold around the world. There are many reasons why the hydraulic percussion rock drill is better, e. g. faster penetration, longer parts life, better drilling control, improved efficiency, no fog, lower noise level, etc. Since there is no exhaust noise there is a significant reduction in overall noise level (Figure 3. 7). An hydraulic-electric fan

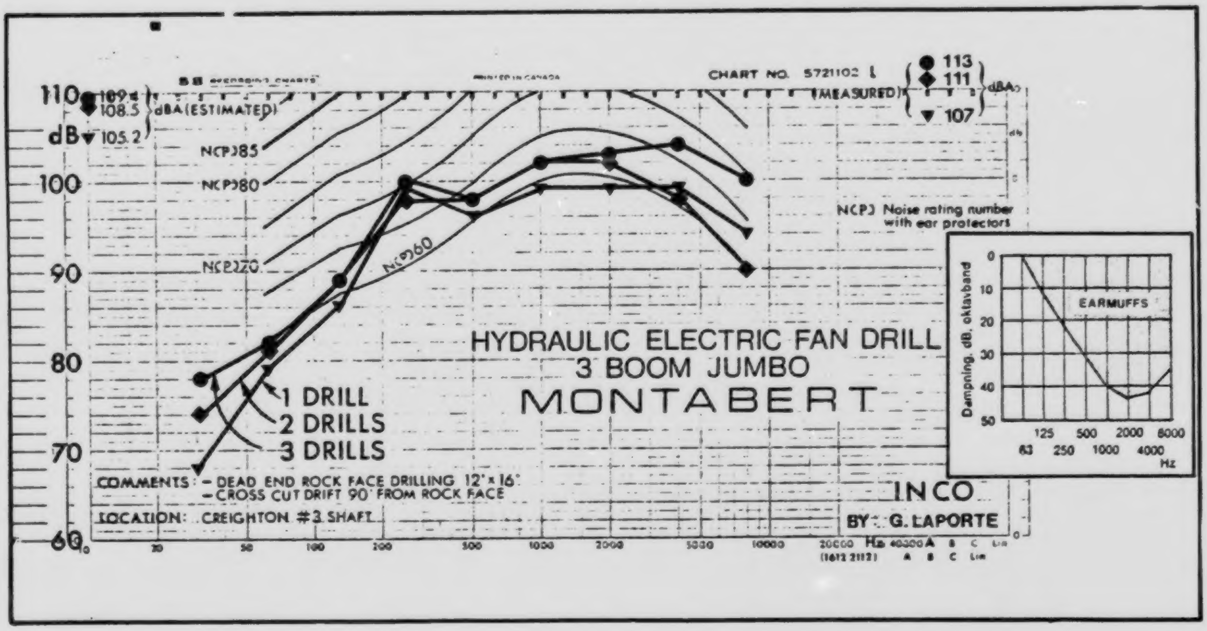


Figure 3. 7: The Noise Spectrum Produced by Hydraulic Percussive Rock Drills (Measured at the Operator's Ear).

drill 3-boom jumbo produces 6 to 7 dBA less noise than the same machine on compressed air (Table 3.2). Noise generated by rock drills creates one of the worst acoustical environments in a mine (Table 3.2).

TABLE 3.2

Noise Surveys in Ontario Mines*

	Frequency in Hz									dBA	
	31.5	63	125	250	500	1K	2K	4K	8K	Meas.	Est'd+
Airleg Drills											
Al-60 (unmuffled)				← 117 Average →						123	122.7
JR-300 (unmuffled)	90	105	112	112	114	119	117	118	120	124	125
AL-60M (muffled)	88	97	112	104	99	104	108	111	110	118	115.5
JR-300M (muffled)	86	102	110	107	106	105	105	111	109	118	115
S-204M (muffled)	83	96	108	105	103	105	109	110	108	117	115.2
Stopers											
RB-83 (unmuffled)	92	107	112	112	107	109	111	111	110	120	117.2
RB-83M (muffled)	89	100	107	106	106	107	108	109	107	117	114.8
SAL-60M (muffled)	97	107	99	104	96	102	106	107	106	116	112.3
R-300M (muffled)	79	97	105	96	96	102	107	109	108	114	113.7
S-250M (muffled)	88	104	102	105	104	107	109	113	109	118	116.8
Drifters											
DH-123 (unmuffled)	95	106	107	116	115	116	116	114	114	124	122.2
DH-123**	80	95	101	105	103	105	109	111	106	117	115.3
COP-119**	98	95	105	108	106	107	111	112	106	117	116.8
				Speech Range							

* Measured at the operator's ears.

** With exhaust manifold and 20-ft length of noise suppression hose.

+ Total noise estimated from the octave-band noise levels given in the first nine columns. Approximate agreement with measured total noise indicates reasonably constant conditions during period of measurement.

These data show the intensity of muffled and unmuffled drills, the noise reduction achieved, and the frequency ranges in which the risk of hearing loss is greatest. Further attenuation is possible.

With varied success, all drilling tool manufacturers are resuming research and development in the field of hydraulic drilling.

3.6.2 Research

Several research projects in the U.S.A. are under way to find a solution to the noise-abatement problem for pneumatic rock drills (25, 26). At the U.S. Bureau of Mines Pittsburgh Mining and Safety Research Centre, there was achieved an abatement system for a stoper drill, which reduces the noise from 115 dBA to 103 dBA.

The Rolla Metallurgy Research Center, U.S. Bureau of Mines, Rolla, Mo., has designed a muffler cover for a sinker. This consists of an alloy rotational chuck liner and a constricted layer damped drill rod that reduces the noise level from 113 to 98 dBA.

U.S. Steel Engineers and Consultants has designed a muffler that reduces the overall noise level of an Ingersoll-Rand stoper drill to 109 dBA (Figure 3.8). Further investigation will reduce mechanical noise to a lower level.

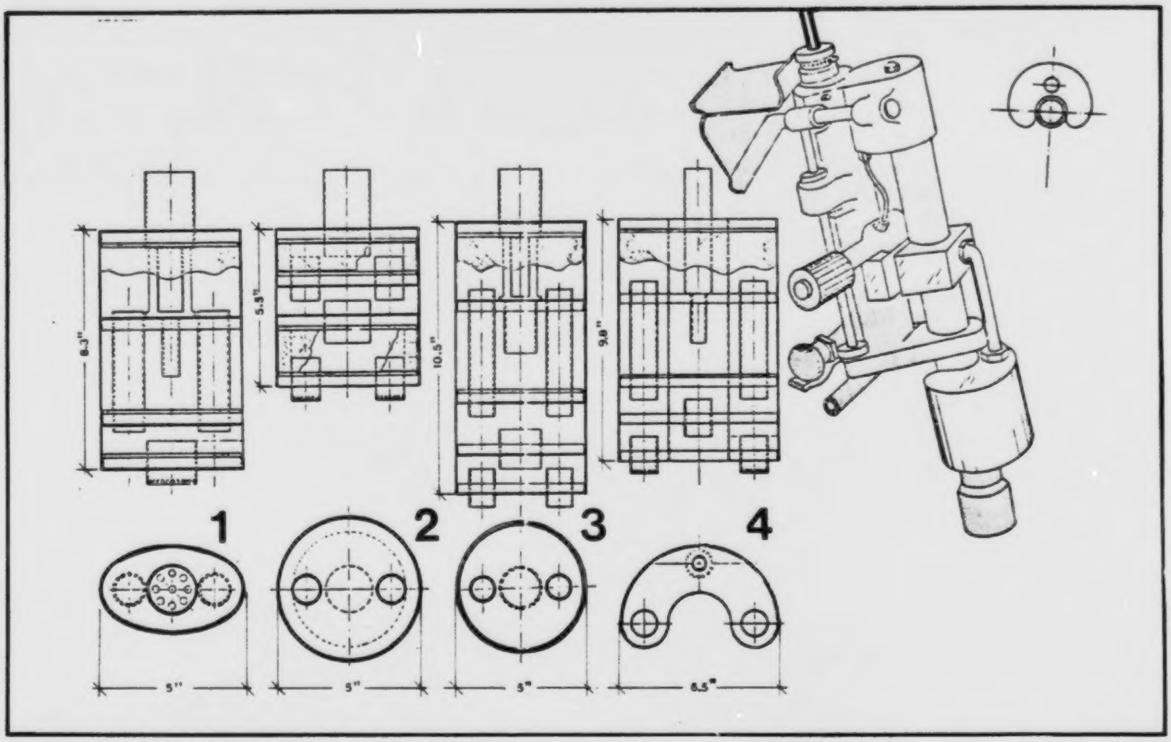


Figure 3.8: U.S. Steel Mufflers Concept for Pneumatic Drill. Exhaust mufflers using expansion and resonant chambers (with results in dBA level): Muffler 1, 108 dBA; Muffler 2, 105 dBA; Muffler 3, 108 dBA; Muffler 4, 108 dBA (25).

The noise emitted by pneumatic hammers, drills and similar machines can be reduced by 7 dBA according to Czechoslovak Patent No. 124,133 (Figure 3.9) (27). The damping system is composed of two air spaces -- one within the perforated inner jacket into which the exhaust air is released, and the other between the two jackets, where the pulsed air flow is smoothed and deflected. The sheath hardly hampers the free expansion of the exhaust air at all, so that it entails little or no loss of performance in the power tool. The inner jacket incidentally collects much of the oil suspended in the exhaust, thus reducing the pollution of the mine atmosphere.

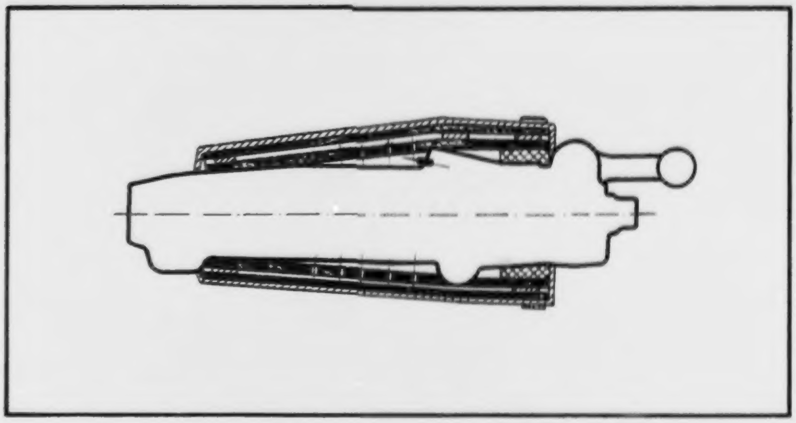


Figure 3. 9: Sound-Damping Muffler and Oil-Absorbing Sheath for Pneumatic Hammers (28).

In Sweden, new efforts are being made to attenuate the noise from heavy jumbo machines and Figure 3. 10 shows a solution offered by Atlas Copco Research (5). At the higher frequencies the attenuation is excellent and probably it could be well applied on hydraulic electric fan drill machines (Figure 3. 7). There is a large range of applications for attenuation of low and high frequencies.

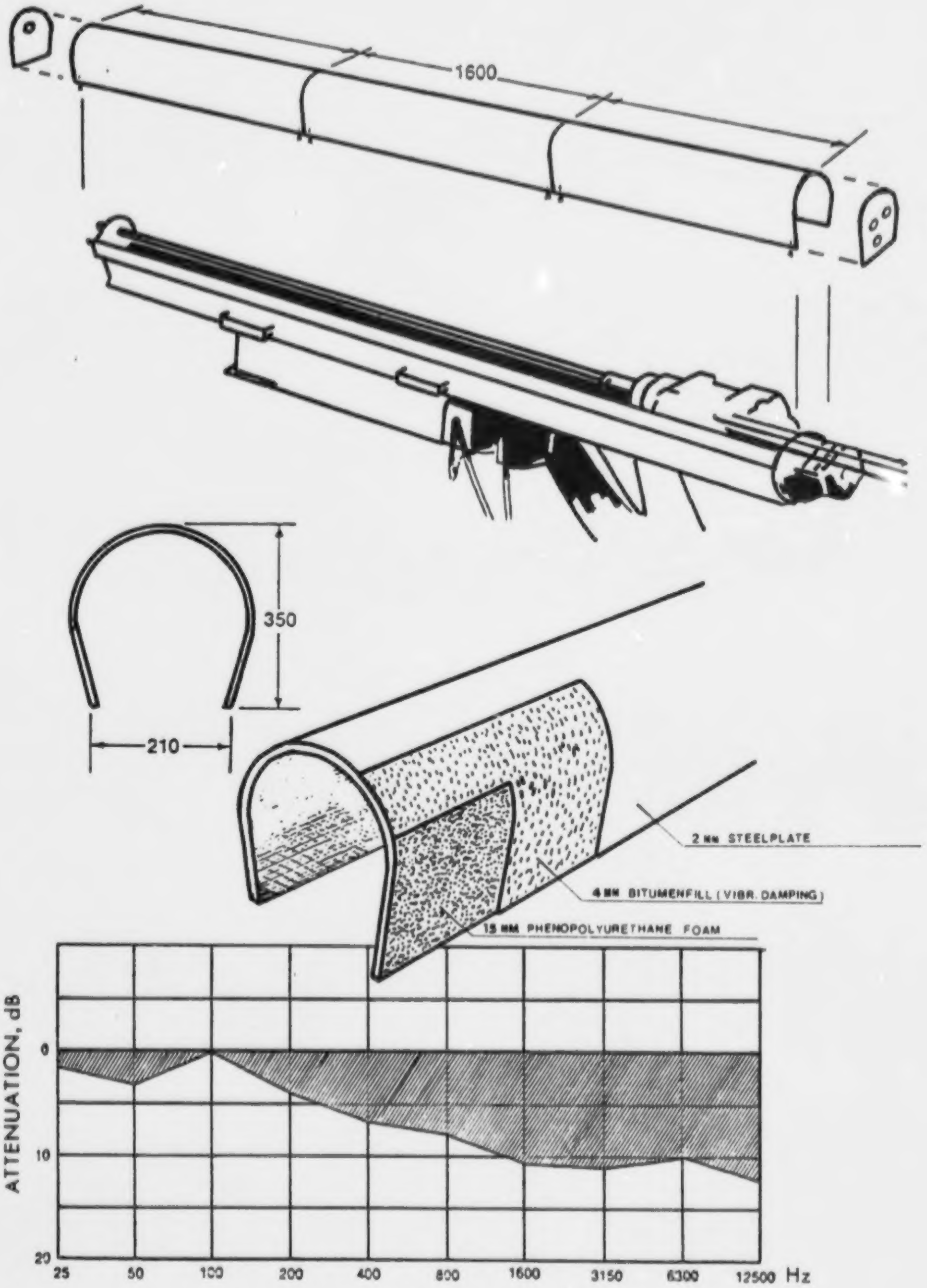

1600
350
210
2 MM STEELPLATE
4 MM BITUMENFILL (VIBR. DAMPING)
15 MM PHENOPOLYURETHANE FOAM
ATTENUATION, dB
0
10
20
25
50
100
200
400
800
1600
3150
6300
12500
Hz

Figure 3. 10: The Sound-Absorbing Enclosure around the Drill Machine (5).

A large number of drills which do not use conventional bits have been designed and tested. The drills have been classified as mechanical, thermal spalling, fusion and vaporization and chemical, according to the way in which they remove rock (28) (Table 3. 3).

TABLE 3. 3

New Drilling Methods

Mechanical	Thermal Spalling	Fusion and Vaporization	Chemical
Abrasion	Jet-Piercing	Atomic Fusion	Hydrofluoric Acid
Electric	Forced-Flame	Electric Arc	
Explosive	Electric-Disintegration	Plasma	
Implosive	High-Frequency Electric	Electron Beam	
Pellet	Induction	Laser	
Spark	Microwave		
Spark-Percussion			
Ultrasonic			

The success of any drill based on a new principal will depend basically on the mechanical efficiency with which it can break rock. The noise associated with its operation, however, is an important additional factor that should influence its development. Some of the methods listed in Table 3. 3 at least have the advantage over mechanical methods that they are inherently quiet.

4. CONCLUSIONS

This review has shown that it is possible to abate the noise level at rock drill machines. To reach the best attenuation one part of the economic criterion has to be sacrificed and the price of rock drills must increase because of special materials built into them.

The tasks of the rock drill manufacturers are:

(1) To evaluate the noise from each machine according to the Standards.

(2) To evaluate the many noise sources peculiar to each machine.

(3) To develop operator enclosures and remote control operations for future products.

(4) To develop quieter components and systems for quieter machines.

The suggested program for future research and development is as follows:

(1) Organize a cooperative effort among federal and provincial governments, noise specialists, mines and rock drilling equipment manufacturers to develop new quieter machines.

(2) Collect information on mining machine noise for use by regulatory bodies, consumers, and information agencies.

5. ACKNOWLEDGEMENTS

Dr. R. Tervo, Research Scientist, Elliot Lake Laboratory, and Dr. W. M. Gray, Mining Research Laboratories, were helpful in many ways. The authors acknowledge the contribution of G. B. Laporte, Sr. Environmental Analyst, International Nickel Company of Canada Ltd., Copper Cliff, Ontario.

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Canada is one of the leading nations in noise abatement in mines

1978

LE CANADA EST L'UN DES CHEFS DE FILE DANS LE DOMAINE DE LA RÉDUCTION DU BRUIT DANS LES MINES

par

M. Savich*

RÉSUMÉ

Pour mieux comprendre la situation du bruit et la protection contre le bruit dans les mines canadiennes, une analyse comparative a été réalisée avec des mines de la Yougoslavie et de l'Afrique du sud. Ces pays ont des systèmes politiques différents, leur population est relativement équivalente et leur industrie minière est avancée. Dans cette brève analyse, on s'est aussi penché sur la situation en Suède et en URSS.

Il ressort de cette analyse que le Canada est l'un des chefs de file dans le domaine de la réduction du bruit dans les mines.

Termes clés : réduction du bruit, mines, Canada, monde.

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CANADA IS ONE OF THE LEADING NATIONS IN NOISE ABATEMENT IN MINES

by

M. Savich*

ABSTRACT

For a better understanding of the noise environment and noise protection in Canadian mines a comparative analysis was made with Yugoslavian and South African mines. These are all countries with different political systems, relatively the same population numbers, as well developed mining industries. In this short review, an analysis was also made with Sweden and the U.S.S.R.

The analysis shows that Canada is one of the leading nations in noise abatement in mines.

Key words: Noise Abatement, Mines, Canada, World.

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1. INTRODUCTION

For a better understanding of the noise environment and noise protection in Canadian mines a comparative analysis was made with Yugoslavian and South African mines. These are all countries with different political systems, relatively the same population numbers, and well developed mining industries. In this short review, an analysis was also made with Sweden and the U.S.S.R.

2. CANADA

1. Noise exposure limits specified in Provincial Governments' regulations are applied in the mining environment. Many machines and installations have noise levels much above the permitted exposure limit and significant reductions have not yet been obtained.
2. A competent authority in the Provincial Governments prescribes the frequency, band number for acoustical measurements, and other monitoring conditions for noise in the mining environment. This monitoring is to be carried out by employers even though mine managements are not always effective in carrying out the task.
3. To satisfy regulations, noise recognized as harmful should be minimized by placing mufflers or exhaust hoses on machinery (Fig. 1). Methods of meeting regulations differ from province to province and mine to mine.
4. The manufacturers have started to make machines and installations that meet noise requirements.
5. Provincial regulations permit the use of personal protective equipment

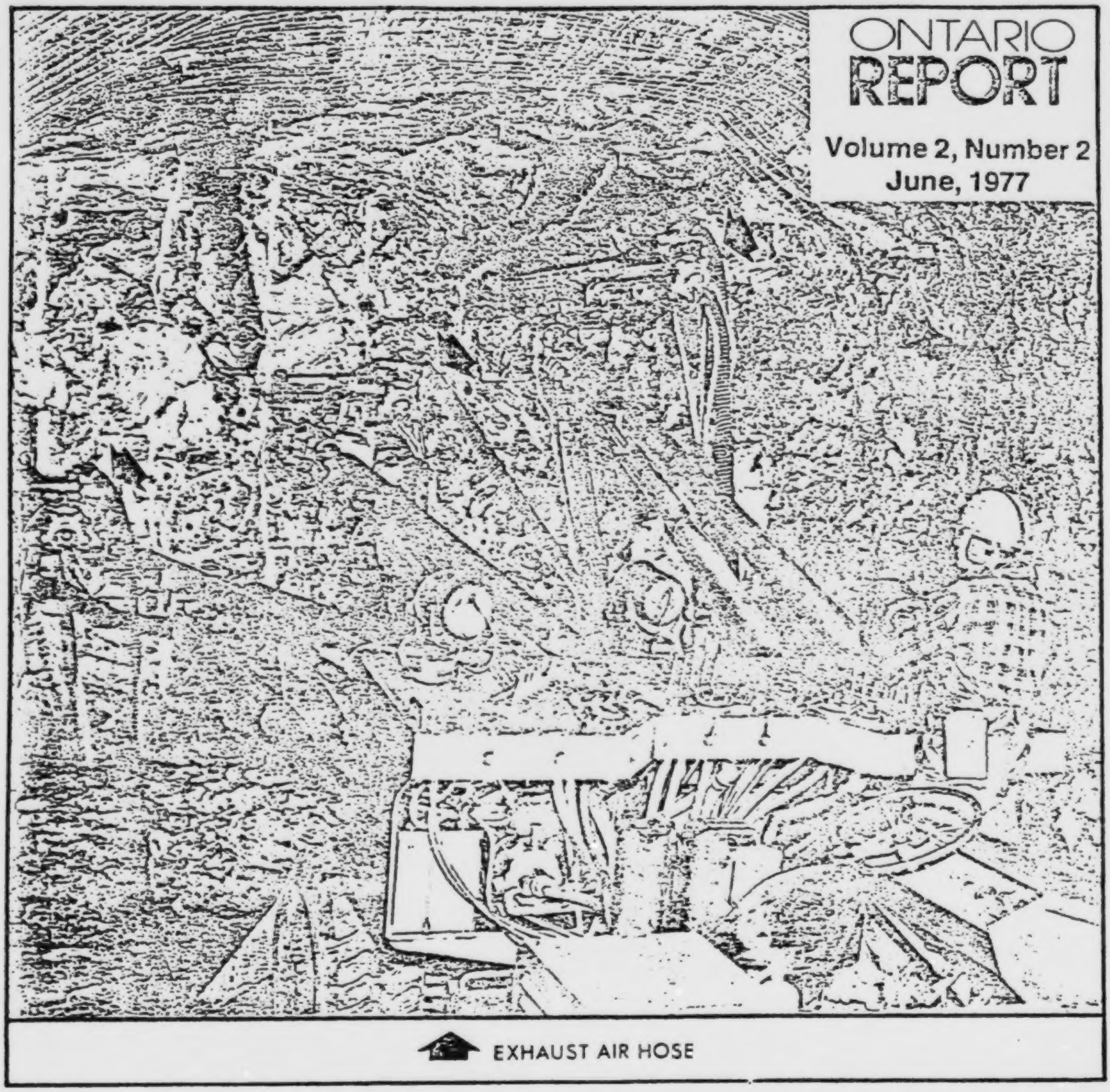

ONTARIO
REPORT
Volume 2, Number 2
June, 1977
EXHAUST AIR HOSE

Fig. 1: A total environment in Canadian mines: roof bolting, good lighting, silencing of exhaust air with hose (~115 dBA), and use of personal protective equipment (ear muffs, glasses, etc.).

(ear plugs and ear muffs) to meet noise control requirements only if reduction by technical or administrative means is not technically feasible.

6. In all mines, audiometric tests are required to be carried out by a competent authority:

a) at pre-assignment examination, and

b) at suitable periodic intervals.

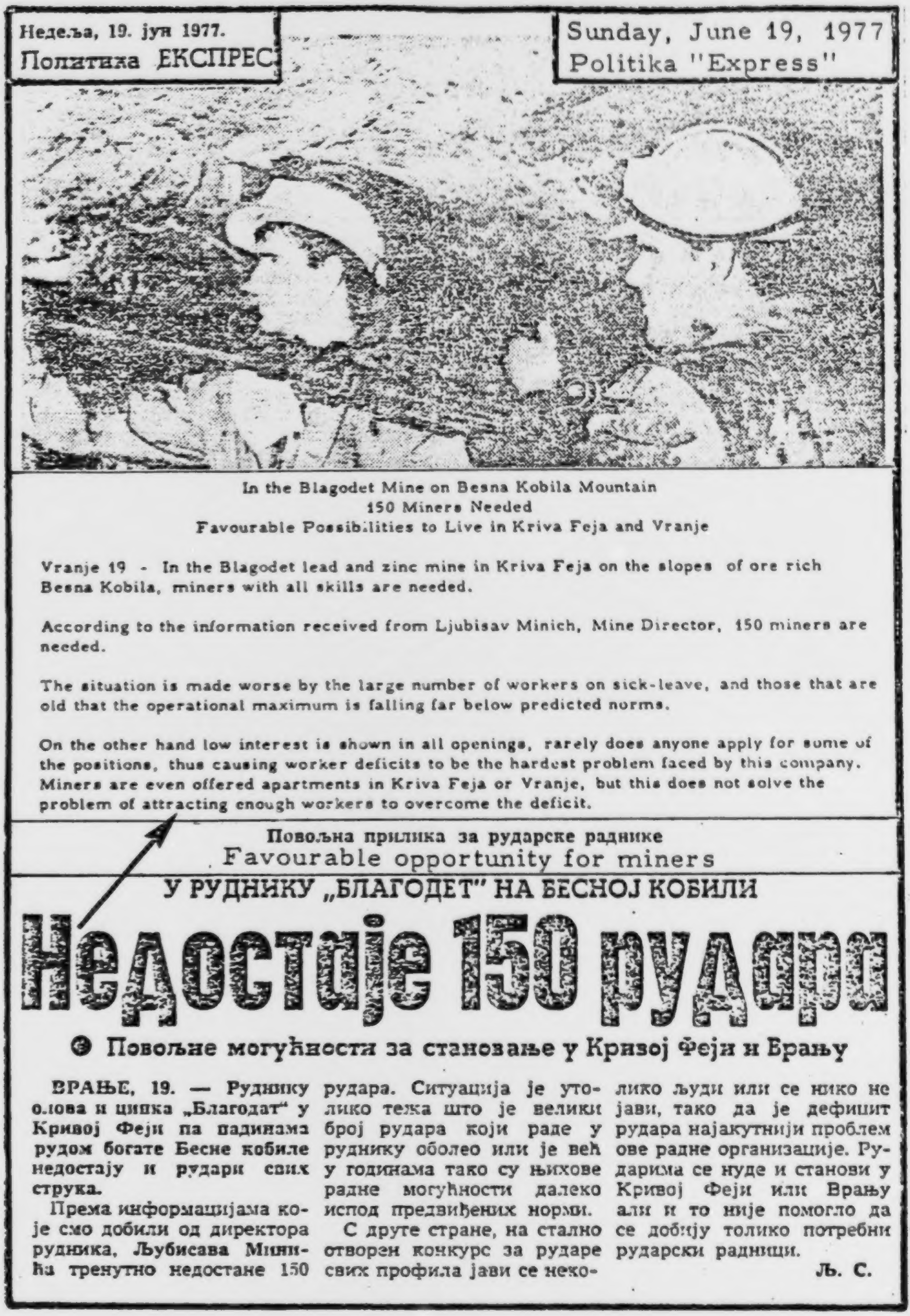
7. Federal and Provincial Governments promote, assist and stimulate research in the field of prevention and control of noise hazards in the mining environment.

8. Employers' and miners' organizations take action to carry out training and information programs to control noise hazards in the mining environment.

Until technical advances and more stringent regulations are made, along with a larger staff of mine inspectors to enforce them, noise will continue to be a health hazard in the Canadian mining industry. Constant, voluntary use of personal protective equipment, such as ear plugs and muffs in all Canadian mines, will guard miners from the threat of hearing loss. Because of this, a new effort has been made to obtain a detailed analysis of ear muffs to improve their application under working conditions.

3. YUGOSLAVIA

1. General precautionary measures and standards for protection at work against noise at working places were accepted by Federal Government (Official Gazette, July 8, 1971), but were never applied in mines and mills.
2. Swedish wool is made available rather than the more effective plugs and muffs (Fig. 2).
3. Workers' representatives are informed and consulted in advance about projects, measures and decisions which are likely to have harmful



Недеља, 19. јун 1977.
Политика ЕКСПРЕС

Sunday, June 19, 1977
Politika "Express"

In the Blagodet Mine on Besna Kobila Mountain
150 Miners Needed
Favourable Possibilities to Live in Kriva Feja and Vranje

Vranje 19 - In the Blagodet lead and zinc mine in Kriva Feja on the slopes of ore rich Besna Kobila, miners with all skills are needed.

According to the information received from Ljubisav Minich, Mine Director, 150 miners are needed.

The situation is made worse by the large number of workers on sick-leave, and those that are old that the operational maximum is falling far below predicted norms.

On the other hand low interest is shown in all openings, rarely does anyone apply for some of the positions, thus causing worker deficits to be the hardest problem faced by this company. Miners are even offered apartments in Kriva Feja or Vranje, but this does not solve the problem of attracting enough workers to overcome the deficit.

Повољна прилика за рударске раднике
Favourable opportunity for miners

У РУДНИКУ „БЛАГОДЕТ" НА БЕСНОЈ КОБИЛИ

Недостаје 150 рудара

● Повољне могућности за становање у Кривој Феји и Врању

ВРАЊЕ, 19. — Руднику олова и цинка „Благодат" у Кривој Феји на падинама рудом богате Бесне кобиле недостају и рудари свих струка.

Према информацијама које смо добили од директора рудника, Љубисава Минића тренутно недостане 150 рудара. Ситуација је утолико тежа што је велики број рудара који раде у руднику оболео или је већ у годинама тако су њихове радне могућности далеко испод предвиђених норми.

С друге стране, на стално отворен конкурс за рударе свих профила јави се неколико људи или се нико не јави, тако да је дефицит рудара најакутнији проблем ове радне организације. Рударима се нуде и станови у Кривој Феји или Врању али и то није помогло да се добију толико потребни рударски радници.

Љ. С.

Fig. 2: Yugoslavian Case:

The miner and his helper have no personal protective equipment (ear plugs and ear muffs). The LION BBC24, Atlas Copco is a powerful, but harmful rock drill (~116 dBA). The silencing version; BBC 25, reduces noise energy by about 75%, but has never been applied in Yugoslavian mines because of a small increase in price.

consequences on the health of miners (such as air pollution, noise and vibration in the mining environment).

4. Authority from Provincial Governments (called Republic Governments) is available for audiometric examinations.
5. Only the mines assist and stimulate research in the mining environment about noise and vibration.
6. National laws provide workers the right to obtain information about and training against occupational hazards in the mining environment (however, managements are ineffective when it comes to implementing this law).
7. Mines inspectors of Provincial Governments enforce strongly air pollution standards. These standards cover all air contaminated by substances, whatever their physical state, which are harmful to the health, or otherwise dangerous. However, in noise and vibration abatement mine inspections are ineffective.

Political speakers say that increasing productivity and raising the standard of living of Yugoslavian citizens is more important. They point out that other rich West countries did little to control pollution in the nineteenth century during their industrial revolution.

The most valuable aid is knowledge of how we have got over the abuses of the nineteenth century. We must realize that with modern industrial development pollution control need not be unduly expensive, and that early action can be an excellent investment.

An now we return to the case of the Blagodet Mine on Besna Kobila Mountain ("Natural Treasure Mines on Wild Mare Mountain") (Fig. 2).

The following information is taken from E/MJ International Directory, Mining Activity Digest; Jan 6th, 1978 (1):

Lead and Zinc

Company	Location	Project	Capacity		Units	Investment	Start	Class
			Planned	Now				
Yugoslav Gov't.	Besna Kobila, Yugoslavia	mi	500M	300M	mtpy ore	D120MM (Can.$7.88 MM)*	1980	AB

NOTE: * Mid market rates in Canadian Funds, April 13, 1978.
(Prepared by the Bank of Nova Scotia)
Can. $1.00 = D15.1515 (D = Dinar).

Abbreviations:

mi - mine
mtpy - metric tons per year
M - thousands
MM - millions

Class symbols:

A - Projects now under construction.
B - Projects with development program, but for which further financing may be required and for which construction has not yet begun.

From this information it is evident that the capacity of 500,000 mtpy ore should be realized by the year 1980. However, due to a shortage of manpower this desired capacity will not be met.

When INCO started the program to protect workers from industrial noise in 1954, the lead-zinc mine, Šuplja Stijena ("Hollow Rock"), in Yugoslavia was opened (2). In 1968, when audiometric hearing tests of miners from "Hollow Rock" were summed up, the results were startling (3). Out of 229 miners and mill workers exposed to noise, only 19 percent were without any hearing loss (40 dBA). The hearing loss of the remainder were distributed as follows: 21 percent in the 5 years-work category, 49 percent in the 10 years-work category, and 80 percent in the over 10 years-work category. These workers did not use hearing protection devices.

Roughly 20 percent of the experienced work force in mining emigrated from Yugoslavia to find jobs where working conditions, pollution control and hygienic conditions are better. Yugoslavia is one of the leading nations in emigration of qualified workers (Table 1).

4. SOUTH AFRICA

1. South Africa, like Canada, is a member of the International Standards Organization (ISO) Technical Committee in Acoustics. Noise exposure limits recommended by ISO were accepted, but were never applied in mines and mills (Fig. 3).
2. Dangerous conditions are caused by an interrupted face advance. Very large stress concentrations are induced near edges of extensive tabular excavations, such as stopes in deep gold mines and longwall faces in coal mines (4).
3. Ventilation cooling systems were applied and some research was done in noise abatement. The great cost of suppressing noise generated by fans in densely populated areas might be reduced by introducing quieter fans (5).
4. Some research in dust pollution was made because of silicosis.
5. Progress has been made with hand-held hydraulic drills (less noise), much lighter than conventional pneumatic drills (6).

The Moodie Report gives new insight on the black miner (7). The study into the life of the black mine worker provides extensive new information on the perceptions, aspirations and dissatisfactions of the ordinary black mine worker.

TABLE 1

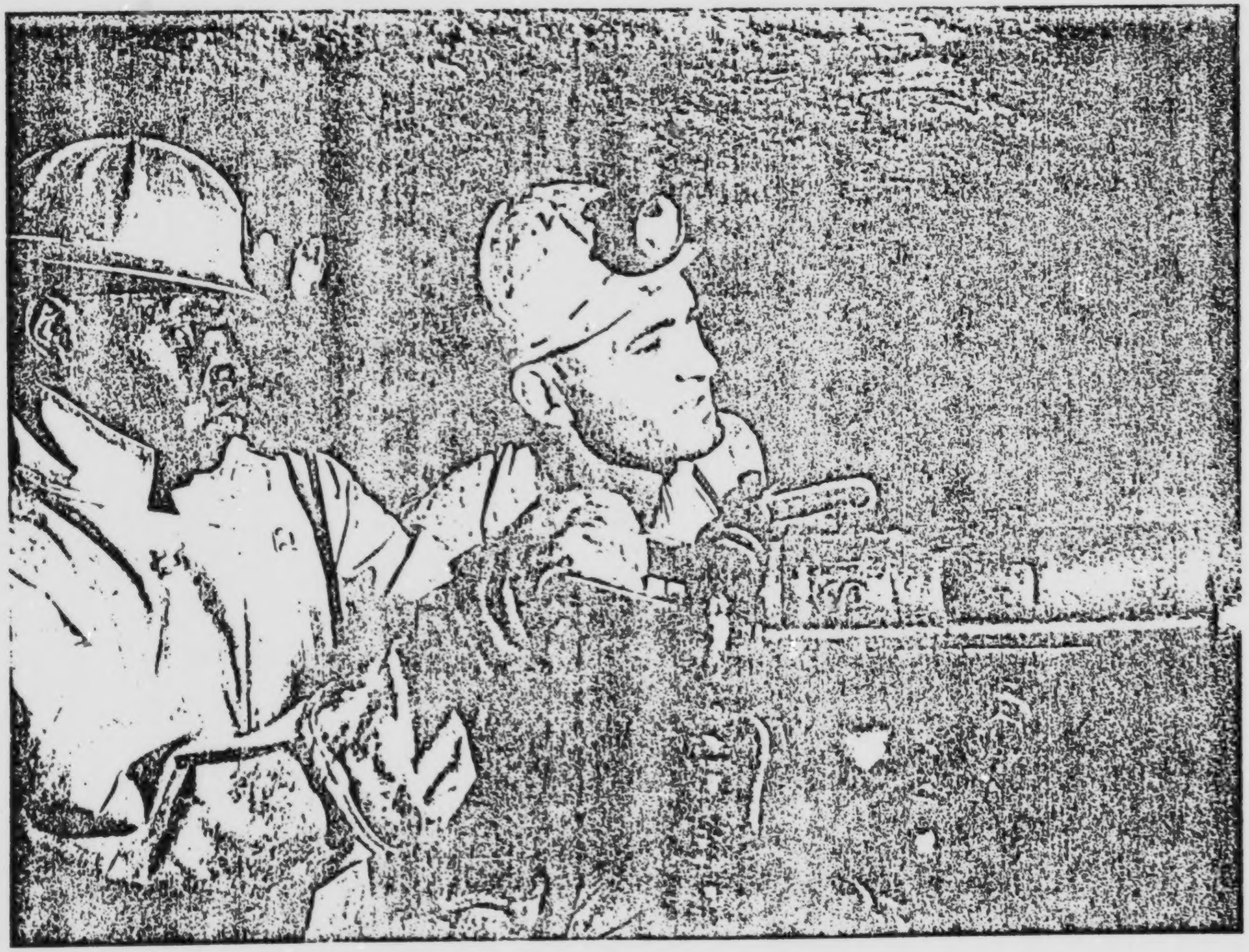
Europe - Immigrant Workers[1]

(figures in thousands rounded off to the nearest 0.5 thousand)

Continents and Countries of Origin	Countries of immigration or employment (excluding "seasonal workers")									Countries of Origin
	Austria	Belgium	France	West Germany	Luxembourg	Netherlands	Sweden	Switzerland	Totals	% of Total Population
Africa										
Algeria	-	3.5	331	1.5	-	-	-	-	335	1.94
Morocco	-	28	152.5	15.5	-	29	0.5	-	225.5	1.26
Tunisia	-	2	73	-	-	1	0.5	-	76.5	1.33
Europe										
Finland	-	-	-	-	-	-	100.5	-	100.5	2.13
Greece	-	10	-	179	-	2	8.5	-	199.5	2.18
Italy	2	96	199	277	11	10	3	262	860	1.53
Portugal	-	6	361	63.5	12.5	5	1	-	449	4.63
Spain	-	30	204	111	2	16	2	68	433	1.20
Turkey	25	16	31	527.5	-	38	3.5	-	641	1.59
Yugoslavia	122	3	42	390	0.5	9.5	26	24	617	2.86
Miscellaneous	21	121	191	372[2]	21	70	80	162	1,044	-
Totals	170	315.5	1,584.5	1,937	47	180.5	225.5	516	4,982	-

[1] Excluding the United Kingdom in view of the special nature of migration in this country.
[2] Including 76,000 Austrians.

Source: OECD: Directorate for Social Affairs: SOPEMI; 1977 Report (Paris), 1977.



(S. A. Mining and Engineering Journal, May 1977; Page 65)

Fig. 3: South Africa's Reality: Black miner and white foreman. The miners have no personal protective equipment (ear plugs and ear muffs). Airleg Drill SECO is one of the most dangerous rock drills (~117 dBA). SECO Co. has no rock drills with a muffler.

It is difficult to make judgements about the concern for hearing loss in South African mines because basic questions about workers have yet to be answered. Some concerns are:

- Tensions and clashes between black miners and white employees;
- Dictatorial systems in mines;
- Housing development (In December, 1966 it was announced that Anglo American Corporations will spend some R20-million to provide accomodation for families of three percent of 'South Africa's 120, 000 black workers);
- The black miners are not treated as equal human beings.

In this case the first step must be to create a just social order and only then to set upon the task of bringing about total environmental control. This is a long-term process.

5. SWEDEN

1. A medical hearing conservation program was started in 1955 which included examining the hearing of all workers. This program is still being carried on in about the same way as when it was introduced (8)(9).
2. More than half the labour force in Sweden is exposed to a level above 85 dBA. The National Swedish Board for Industrial Safety prescribes further investigation by octave band analysis if there is a risk of hearing damage caused by noise.
3. Actions are as follows:
    - technical measures to reduce exposure to noise;

- prescription of ear protectors;
- individual job placement on the basis of sensitivity to noise and state of hearing ability; and
- regular hearing control.

4. Full control of measures taken is in the hand of Swedish Unions. A worker is informed immediately after each audiometric test. Equal measures are taken in the entire mining industry. All results are made public.
5. Sweden is the leading nation of the world in noise abatement.

6. U.S.S.R.

1. Researchers have been compiling data over the last 30 years on the physiological effects of vibration. Small effort has been made in noise abatement.
2. Since after the Second World War, the U.S.S.R. began to build machines for large industrial and military use. Problems of vibration reduction and isolation have engaged engineers. Some engineering control was applied to noise abatement (10).
3. E. Mastromatteo noted that in the U.S.S.R. sanitation norms for noxious gases in mining operations are too strict, and that they are unattainable (11). The author is of the same opinion after having read Russian acoustics literature.

A. P. Filin mainly investigated heavy and medium rock drill noise (Table 2) (10). For ear protectors in Russian mines, a silicone polymer

TABLE 2

Level of Intensity and Spectral Composition of the Noise Generated by Self-propelled Mining Machines (10)

Working Operation	Mean Noise Level (dB)	Prevalent Frequencies Hz	Excess of Sanitation Norm (dB)	Sanitation Level* (dB)
Drilling with jumbo drill of the type:				
"Meninghof" ✱	123	1000 - 8000	48	75
"Climax" ✡	117	500 - 4000	42	75
SBK-4 ◆	127	2000 - 8000	53	74
BBK-4 ◆	123	500 - 4000	48	75
SBU-2 ◆	114	1000 - 8000	39	75
Drilling with rock drills:				
PR-30k ◆	120	1000 - 4000	45	75
PR-241 ◆	124	500 - 4000	49	75
Loading ore into mine cars (self propelled) with excavator:	103	520 - 2000	24	79
- discharging ore into bunker	95	1000 - 2000	16	79
- bulldozer operation	102	500 - 2000	23	79
- operation of loader with collecting arms	104	500 - 2000	25	79

Note:
- * Evaluation by M. U. Savich
- ✱ Made in Germany (D. D. R.)
- ✡ Made in U. S. A.
- ◆ Made in U. S. S. R.

substance is utilized by each worker through a dispensing machine. Because of lack of data on the attenuation characteristics on Russian polymers, we took American data for polymer hearing protectors into consideration (Table 3). The attenuations are similar. If we compare theoretical attenuation characteristics from Table 3, which are less in practice, with the excess of sanitation norm, we can conclude that the sanitation level is not always attained.

In the same publication, the efficiency of mufflers is demonstrated (Table 4). Effectiveness of noise suppression beyond 26 dB is unknown to the world presently. The U.S. Bureau of Mines, Pittsburgh Mining and Safety Research Centre, and the Rolla Metallurgy Research Center, U.S. Bureau of Mines, Rolla, Mo., attained the largest attenuation from 12 dBA and 15 dBA (12)(13). Technically, as is shown in the publication, attenuation is unattainable beyond 26 dB on any frequency.

4. Two years ago, new sanitation norms were introduced which are very similar to those of OSHA*. Now norms are the real reflection of the state of the art, and the entire problem is posed realistically.

7. CONCLUSIONS AND RECOMMENDATIONS

1. The short analysis demonstrates that differences in noise abatement between nations in industry, particularly in mines, exist. This is a reality of our time.
2. Canada is one of the leading nations in the fight against noise pollution.

---

* The Occupational Safety and Health Act (U.S.A.).

TABLE 3

Attenuation Characteristics of Two Types of Polymer Hearing Protectors

Pure Tone Frequency (Hz)	Polymer Hearing Protector				
	Peacekeeper* General Electric		Insta-Mold* Prosthetics Inc.		
	Attenuation (dB)		Attenuation (dB)		
	Mean	St. dev.	Mean	St. dev.	
125	18.0	5.3	19.9	3.9	
250	16.3	3.9	26.9	4.4	
500	17.9	6.4	30.5	6.1	
1,000	20.1	4.8	30.6	4.5	
2,000	35.5	5.7	35.7	2.3	Similar Attenuations
3,000	40.5	5.4	38.9	5.3	
4,000	44.1	5.5	44.6	4.7	
6,000	40.0	8.6	40.0	5.0	
8,000	35.4	9.4	37.5	5.5	

Note: *ANSI Z24-22-1957 (standard test).

TABLE 4

Effectiveness of Mufflers (10)

Type of Muffler	Mean Noise Level (dB)	Prevalent Frequencies Hz	Effectiveness of Noise Suppression (dB)
Rock drill PT-45 ◆			
- without muffler	119	500 - 1000	
- with muffler	110	1000	9
Rock drill PR-30k ◆			
- without muffler	122	500 - 4000	
- with G-3 exhaust muffler	103	125 - 2000	19
Jumbo drill SBU-2 ◆			
- without muffler	122	2000	
- with muffler	96	2000	26
Rock drill PK-35v ◆			
- without muffler	122	2000 - 4000	
- with G-4 muffler	112	500 - 1000	10

Note: ◆ Made in U.S.S.R.

3. To quicken the progress in noise abatement, it is necessary to know the achievements and goals of others.
4. In a world of rapid population growth, economic and social factors will affect the total environment; and conflicts between developed and developing countries will presumably remain till the year 2000 (14).
5. Man does not live by safety alone. Zero risk and absolute safety are indeed costly illusions. Abatement costs are higher in developed countries, where the cost may range from 2 to 4% gross national product (e.g., U.S.A.).
6. For this goal: open discussion and constructive criticism of new proposals for the betterment of noise environments in Canadian mines, is needed. This can serve as solid base for further advancement.

8. ACKNOWLEDGEMENTS

The author acknowledges the suggestions of Dr. R. Tervo, and Dr. J. Bigu, Research Scientists; and Dr. N.K. Davé, research fellow, Elliot Lake Laboratory, CANMET, E.M.R., Elliot Lake in the preparation of this report.

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VOL. 5 Report 4

Heathwood Engineering Associates.

Diamond drill noise study phase 1

CANMET Contract No. OSQ79-00117

Rep. No. 9-9023 (1979)

This project planned and funded

by

The Mining Research Laboratories

CANMET

Department of Energy, Mines & Resources

OTTAWA

DSS Serial No. OSQ79-00117

DSS File No. 22SQ.23440-9-9023

CHAPITRE 1

HISTORIQUE

Introduction

Il est presque impossible de trouver une perforatrice au diamant qui fonctionne sans produire une intensité de bruit si élevée qu'elle risque d'endommager gravement l'audition de l'opérateur. Ce dernier travaille toujours près de l'équipement alimenté par une importante source d'énergie généralement non isolée. Bien que des mesures aient été prises pour améliorer cette situation, elles n'ont pas été suffisantes pour satisfaire aux exigences légales imposées dans tout le pays. Le 9 novembre 1979, CANMET, le Centre de recherches minières d'Énergie, Mines et Ressources à Ottawa, a octroyé un contrat pour l'étude de la réduction du bruit produit par des installations de sondage au diamant. Cette étude avait pour objectif de cerner le problème en termes précis, d'analyser les données et les techniques existantes et, en général, de jauger la situation actuelle de l'industrie en matière de réduction du bruit.

Portée du contrat

Afin d'évaluer complètement la situation dans l'industrie, des enquêtes ont été effectuées auprès de fabricants et d'utilisateurs de perforatrices. Pour ce faire, on a conçu une formule qui a été postée à environ 60 entrepreneurs et sociétés minières du Canada et des États-Unis. Presque tous les entrepreneurs canadiens ont été joints par cette enquête. Par la même occasion, on a établi une liste sommaire des équipements de sondage disponibles. D'importants fabricants d'équipements de sondage et des fabricants de pièces auxiliaires telles que les moteurs ont été consultés dans cette partie de l'enquête.

Des recherches de documents et de brevets ainsi que des organismes de réglementation des intensités de bruit dans l'industrie de sondage au diamant ont été réalisées. La recherche de documents et de brevets s'est limitée aux informations liées aux problèmes ou à la réduction du bruit produit par les perforatrices au diamant et aux problèmes ou à la réduction du bruit par les composantes. Seuls les organismes des gouvernements provinciaux ont été consultés à cette fin.

CANADIAN DIAMOND DRILL NOISE STUDY

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CHAPTER 1

BACKGROUND

Introduction

It is almost impossible to find a diamond drilling operation which is not associated with high noise levels. These high noise levels can seriously damage the operators' hearing. The operators are always in close proximity to the equipment which is powered by a large generally unisolated power source. While efforts have been made to improve the situation, these have not been sufficient to adequately meet legal requirements throughout the country. On November 9/79, CANMET, the Mining Research Centre of Energy, Mines & Resources, Ottawa, awarded a contract to study noise reduction on diamond drill installations. The object of this study was to define the problem in specific terms, to research existing data and techniques and in general, to gauge the industry's current status with respect to noise reduction.

Scope of the Contract

In order to fully evaluate the industry's position, surveys were made of both manufacturers and users of drilling equipment. This was accomplished by designing a form that was subsequently mailed out to approximately 60 contractors and mining companies in both Canada and the U.S.A. Almost all of the drilling contractors in Canada were contacted in this survey. At the same time, a summary was made of available drilling equipment. Leading manufacturers of complete drilling equipment and manufacturers of sub-components such as engines and motors were contacted in this part of the survey.

Both literature and patent searches were completed as well as a search of agencies regulating noise levels for the diamond drilling industry. The literature and patent search was limited to information pertaining to diamond drill related noise problems or abatement and component noise problems or abatement. The agencies were exclusively those of the governments of each province.

Joint Project Responsibility

The project was awarded jointly to Heathwood Engineering Associates Limited, Consulting Engineers, and Noranda Research, located at Pointe Claire, Quebec. Noranda Research, through the Noranda companies, is actively involved in diamond drilling and noise control. Heathwood Engineering is actively designing equipment for diamond drilling and other manufacturing industries. Both companies consequently have combined skills regarding all facets of design and use of the drills as well as competence in analysis and abatement of noise sources. Noranda Research has extensive lab facilities and equipment.

Contract Measurements

While measurements, in the well defined sense, were not within the scope of this project, general measurements to obtain overall data were included. These measurements were completed on surface diamond drilling equipment, generally diesel powered, and on pneumatically powered equipment underground. While this work was not extensive, it did tend to verify the data obtained from other sources.

The final portion of the work was to recommend changes and establish ongoing research work. Without detailed measurements, it is difficult to make exact recommendations, however, with the limited data available in this phase, it was possible to reach general conclusions relative to noise abatement on diamond drilling equipment.

CHAPTER 2

THEORETICAL CONSIDERATIONS

Nature of Noise

In discussing the problem of silencing air motor exhaust a noted authority in the industry summed up the problem of noise reduction as that of receiving a gift which turned out to be a box within a box, within a box. He pointed out that, to find out what your gift is, you have to open all the boxes. Noise is quite similar to this analogy. If several equally loud sources of noise are contributing to an overall noise level, silencing only one source will have a small effect on the overall noise level. It is necessary to silence them all to achieve significant noise reduction. It is important to realize that noise adds logarithmically and not algebraically. For instance, 106 decibels can be achieved with two 103 decibel sources. The significance of this is that it may seem reasonable that the exhaust system is causing the noise and should receive the most effort. However, once the noise of the exhaust system is taken away, the sound level could still be nearly as high. The only proper way to reduce noise is to first evaluate all of the sources in terms of sound power, and then eliminate or reduce them to a sufficient level so that in concert, they do not exceed the allowable limit.

Sound is measured in decibels denoted (dB). The decibel can be defined as 10 log (I/I_o) where I is the sound intensity in Watts/m^2 and I_o is a reference intensity of 10^{-12} Watts/m^2. It is characterized in accordance with its frequency spectrum (pitch) and its variation with time. In order to agree as closely as possible with the way in which the ear responds to different sound frequencies, a sound level meter applies a frequency weighting system, called A-weighting, to the signal. Measurements in A-weighted decibels are denoted dBA. This is the standard method of quoting sound levels. Figure 1 shows sound levels associated with various activities.

Problems Associated with Noise

On the positive side, noise has the advantage of indicating all is well with machinery because through operator experience "it sounds right". This should not be taken as a reason for avoiding hearing protection. Operator experience wearing hearing protection can lead to the same capability of knowing when a machine "sounds right". This

Fig. 1 — Common noise levels and typical reactions

Sound Source	Noise Level	Apparent Loudness	Typical Reaction
	dBA 135		Painfully loud
Military Jet	130	Sixty-four times as loud	Limit amplified speech
Jet takeoff at 200' or typical pneumatic drill	120	Thirty-two times as loud	
	110	Sixteen times as loud	Maximum vocal effort
Typical diesel drill	105		
Jet takeoff at 2,000'	100	Eight times as loud	
Freight Train at 50'	95		
Heavy truck at 50' Busy city street	90	Four times as loud	Very annoying Hearing damage (8 hours)
	80	Twice as loud	Annoying
Highway traffic at 50'	70	Base reference	Telephone use difficult
	60	Half as loud	Intrusive
Light car traffic at 50'			
Noisy office	50	Quarter as loud	Speech interference
Public Library	40	Eighth as loud	Quiet
Soft whisper at 15'	30	Sixteenth as loud	Very quiet
	10	Sixty-fourth as loud	Just audible
Threshold of hearing	0		

Adapted from C.M.H.C. publication NHA 5156 12/77
Road and Rail Noise: Effects on Housing

NOTE: The minimum difference in noise level that is noticeable to the human listener is 3 dB. A 10 dB increase in level appears to double the loudness while a 10 dB decrease halves the apparent loudness.

Figure 1

is especially true where co-ordination is required between only a few people. However, there is no question that high sound levels can seriously damage hearing. Generally, the effect depends on the loudness of the sound and its duration. In other words, a sound at a lower noise level can be endured for a longer time than a sound at a high noise level. Table 1 shows maximum allowable sound levels which have been in use throughout much of North America for unprotected workers. At present, many provinces are changing or have changed to limits 5 dBA below the ones shown. No worker should be exposed to sound levels beyond 115 dBA. Noise levels are discussed in more detail later in this report.

The problem of evaluating the noise level in terms of duration is never quite as simple as it may at first seem. Under actual field conditions, noise levels vary so that some form of "averaging" must be done before comparisons can be made with the regulations. To obtain an average, a device known as a dosimeter has been developed. This device is placed on the operator and at the end of the work period can be read out to provide a figure which indicates a single 8-hour averaged sound level that can be compared with the required provincial regulation.

Two different schemes have been evolved to average the random sound levels into one equivalent 8 hour dBA figure. One method known as the equivalent sound level, or L_{eq}, (used in Europe) provides a time, sound level trade off using the formula:

$$(1) \quad L_{eq} = 10 \log \frac{1}{8} \int_{o}^{T} 10^{\frac{L(t)}{10}} \cdot dt$$

The other method is known as L_{OSHA} (used in the U.S.A.) and is given as

$$(2) \quad L_{OSHA} = 16.61 \log \frac{1}{8} \int_{o}^{T} 10^{\frac{L(t)}{16.61}} dt$$

where L(t) = INSTANTANEOUS SOUND LEVEL IN dBA AT TIME t

and T = TOTAL TIME OF EXPOSURE PER DAY IN HOURS.

Table 1

Maximum Allowable Sound Levels
Currently in Use Throughout
North America*
(for unprotected workers)

Sound Level	Duration/Day
85 dbA	16 hours
90	8
95	4
100	2
105	1
110	1/2
115	1/4

*Note that many jurisdictions are now reducing or planning to reduce these limits by 5 dBA.

See for instance Cyril M. Harris, Ph. D., "Handbook of Noise Control" McGraw-Hill second edition.

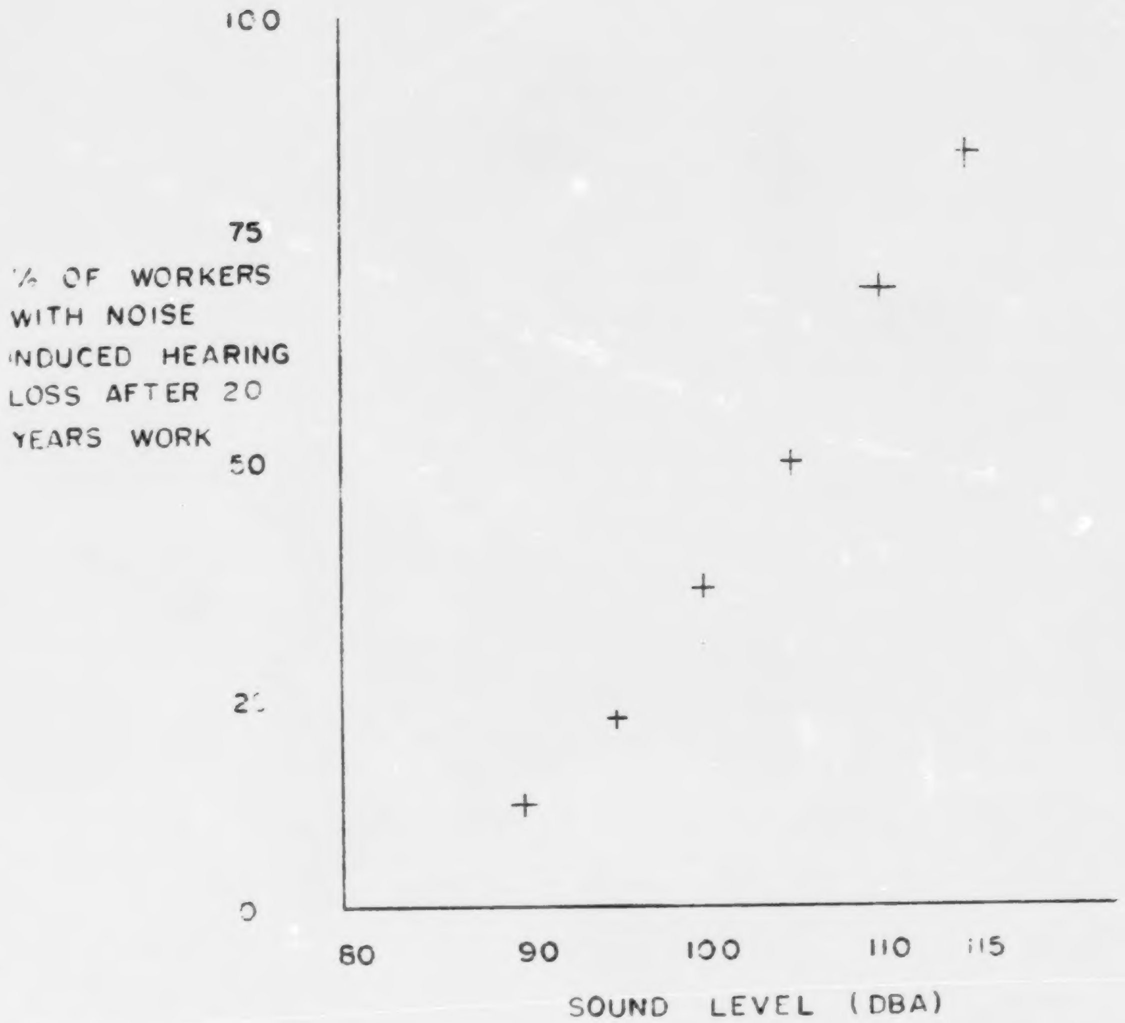

FIGURE 2

Adapted from: M.V. Crocker & A.V. Price,
Noise and Noise Control, Vol. I,
CRC Press, Cleveland, Ohio, 1975.

Workers exposed to high noise levels suffer progressive loss of hearing over their working lives. Figure 2 shows hearing loss after 20 years versus average sound level.

Review of Noise Control Techniques

There are a number of methods of reducing the noise level. The one most commonly used is hearing protection in the form of ear muffs or earplugs. These have the advantage of being relatively cheap and portable. They are also subject to both misuse and abuse, particularly when the work cannot be supervised on a full time basis. Very few of the operators on the surface rigs visited, were wearing the muffs that they had in their possession. Hearing protection is also limited in its ability to reduce sound, even for good equipment. At best, they offer protection up to a sound level of 100 - 105 dBA for ordinary muffs and 105 - 110 dBA for muffs and plugs or what is commonly called "double protection".* Most regulatory authorities recognize these facts and consequently allow hearing protection only as an interim measure.

Noise can also be reduced by placing a barrier between the noise source and the operator. This may take the form of a wall between the equipment and the operator, or an enclosure of steel, thick plywood or similar material over the equipment. Enclosures have the disadvantage that they are cumbersome and, unless very carefully designed, will affect the accessibility of the equipment.

It is essential that any cover made for the purpose of noise abatement be absolutely leak-free. Even a small hole can seriously deteriorate the ability of an enclosure to function properly. Where an opening must be left in an enclosure for ventilation or other purposes, a commercial silencer or custom designed sound trap may be used to prevent sound from escaping.

It is also necessary to line any enclosure with a sound absorbing material, such as fiberglass, to soak up the sound trapped in the enclosure. This may be protected with perforated metal and very thin plastic or foil to prevent damage and soaking.

When an enclosure or wall is used, it is important that vibration isolators be used to prevent vibration from "short-circuiting" the enclosure by travelling through the floor or walls and producing sound outside the enclosure. Spring mounts, rubber mounts and separate foundations are common methods used.

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*Based on results discussed on page 5-3.

Sometimes sound radiating surfaces can be lagged with fiberglass covered with a limp, dense material to reduce noise.

Finally, some sheet metal components may drum when excited by vibration. This can be reduced by adding stiffeners by applying various proprietary damping compounds.

A wall between the operator and the equipment is exactly the same as an enclosure. It carries with it the same penalties as the enclosure in that it makes the equipment less accessible, especially from the control point of view and more cumbersome. The wall must also be leak-free so that all of the sound is contained on the equipment side.

Most of the enclosures used for drill shacks and certainly the underground spaces are highly reverberant. Much in the same manner that bright light is reflected from a mirror, sound is reflected from hard walls. Like an echo, it keeps reflecting and adds to the intensity of the noise heard by the operator. This increase can be as high as 5 dBA for plywood walls in the types of enclosures used for drill shacks. By using a sound absorbing material such as fiberglass on some of the walls, the intensity of the noise can be reduced. Any material used to protect the fiberglass must either be perforated or extremely light and thin.

Sound levels may also be reduced by utilizing types of equipment which do not emit as much noise. For instance, presently electric motors are generally quieter than internal combustion engines and internal combustion engines are generally quieter than air motors. It would appear that a considerable amount of research by respective component manufacturers is being done into quieter internal combustion engines and air motors which, if they become available, could also help the situation.

CHAPTER 3

INDUSTRIAL SURVEY

Survey Methods

By using both mailed-out forms and direct contact, a survey was made of the diamond drilling industry, contractors, end-users, equipment manufacturers and sub-component suppliers. A copy of the mailed out form and the covering letter is shown in Appendix A. In all, 60 of these forms were mailed out to both contractors and mining companies. 35 of these were returned. Direct contact was made, both by telephone and by field trips. Further data was compiled on equipment supplied by major diamond drill manufacturers such as Boyles, Longyear, J.K. Smit and Acker. This information was summarized in terms of power source, (pneumatic, internal combustion, etc.), HP, rated RPM and drive type. Automotive and air motor equipment suppliers were contacted with respect to noise control methods pertaining to their equipment.

Goals of the Questionnaire

The primary goal of distributing a questionnaire on noise to drill users was to find out what the situation was in the industry concerning noise exposure and its control. The questionnaire explored four areas:

1. The type of equipment used in the industry, especially the prime movers.
2. The environment in which drillers work.
3. Noise control measures employed.
4. The human and legal environment concerning noise.

Response

The questionnaire was sent to 60 companies. The response is shown in Table 2. There were 34 drilling companies listed by the Canadian Diamond Drilling Association and 26 mining companies chosen from a list of mining companies. In total 35 out of 60 companies responded.

TABLE 2

RESPONSE TO QUESTIONNAIRE

	RESPONDED	DON'T DRILL	NO RESPONSE
Diamond Drilling Companies:	13	4	17
Mining Companies:	8	10	8
TOTAL:	21	14	25

TABLE 3

(based on answers to questions 1,4,5 in the questionnaire)

USE OF MOTORS

	DRILLS	PUMPS	WIRE-LINE HOISTS
Diesel	289	366	0
Pneumatic	100	57	14
Electric	22	12	0
Gas	10	110	9
Driven by Drill (chain, gear, power take-off P.T.O., hydraulic)	-	55	208
TOTAL:	421	600	231

MOTOR MANUFACTURER (Drills Only)	NUMBER USED	PERCENT OF TOTAL
Ford	104	36%
GM	62	21%
Detroit	45	16%
Hatz	35	12%
Deutz	33	11%
Perkins	5	2%
Lycomin	4	1%
Caterpillar	1	<1

Of the 34 drilling companies, 17 responded and 13 filled out the questionnaire. The other 4 did not do contract diamond drilling.

Of the 26 mining companies, 18 responded, but only 8 of these actually did diamond drilling themselves. Of the remaining 10 responding, 4 volunteered the information that they contracted out their diamond drilling.

Summarized Answers to Questionnaire

The detailed results of the survey are given in appendix B. Only a brief sketch of the major results will be given here. Because some items were left blank on certain questionnaires, totals from different tabulations may not agree. The numbering system: Q1, Q2, etc. refers to the number of the question in the questionnaire. The answers to some questions were not summarized directly but were used in evaluating the answers to other questions.

Equipment Used

Over half the 423 drills used by the companies surveyed are made by Boyles Dresser Ltd (64%). Longyear produces another 22% of the drills. See Q1 in appendix B for more details. Of these drills, 69% are diesel driven, 24% pneumatic, 5% electric and 2% are gas driven. Table 3 summarizes the above and gives the breakdown for pumps and wire line hoists. Most pumps are diesel driven (61%), 18% are gas driven and 9% driven by the main drill drive. The drill drive also powers 90% of the wire line hoists.

Environment

Most (73%) of the drills surveyed are used on the surface, and we believe, at least at the present time, this to be representative of the industry as a whole. Of these, 66% are used in a wooden drill shed, 23% in a canvas shed (which can be quite reverberant) and 8% in a partial shelter. We can conclude that 92% of the drillers work in a reverberant environment. In drill sheds drillers are estimated to be 2' from the drill, 4-5' from the engine (usually diesel) and 8' from the water pump. The exhaust is piped out of the shed. Underground the drillers are 2-3' from both drill and pneumatic motor. The exhaust is often piped over 20' away. Some diesels were used underground and were located over 15' from the drill.

Noise Control Measures Used

Noise control measures are not widely employed. Exhausts are always piped away. Most diesel and gas engine exhausts are fitted with a muffler (81%) of some sort and 67% of the pneumatic motors have some sort of exhaust silencer. The only other noise control measure mentioned by those surveyed is the availability of hearing protection. Every company appears to make hearing protection available to its employees. Ear-muff protectors are almost universally available and some companies also issue ear plugs. However, the use of these measures varies. Averages of the percent usage estimated by the various companies are 72% for surface drillers and 100% underground. On the surface drills visited during the study, use of hearing protection was minimal.

Excuses given for not using muffs include inconvenience, discomfort, laziness, pain and a different perception of noise when using them.

The Human Environment

About 42% of the companies have had complaints about noise from their own operators, and 29% have had complaints when drilling near habitations. In such situations some indicated that they had taken special measures such as better mufflers or day shift drilling only. There have also been some complaints (26% of companies surveyed) from nearby workers underground.

Of the 20 companies which responded, 9 (or 45%) have had workmen's compensation claims.

When asked about noise regulations, 16 out of 20 companies knew they were subject to noise regulations and 13 could identify the agency responsible. However, only 6 of the 20 companies had ever been contacted concerning noise.

Equipment Manufacturers and Sub-Component Suppliers

The drilling equipment suppliers are starting to deal with the problems of noise, with at least three companies having active programs.

As indicated above, both automotive and air-powered equipment manufacturers were contacted relative to noise abatement work on their particular components. The most advanced work appears to be done on automotive equipment, particularly diesel engines. However, while the technology is advancing, as will be reported in a later section of this report, there is nothing new available that could be used on present equipment.

Air motor suppliers also have well advanced sound abatement programs particularly in the design of the motor for quieter operation by adjusting timing, exhaust port design and through the use of mufflers and noise reducing jackets.

CHAPTER 4

LITERATURE & PATENT SEARCH

Introduction

A literature and patent search was undertaken at the Noranda Research Centre. Information relating directly to noise abatement on diamond drilling and to sub-components that could be utilized in this respect, were both researched. It was discovered that most of the information available was directly related to diesel engines, particularly to heavy truck noise. While the noise problems and their solutions are not entirely related to diamond drilling, these papers do contain a considerable amount of useful information relative to noise emitted from diesel engines. Several papers were also obtained on reducing noise from pneumatic motors. Only 2 papers related directly to diamond drills. One of these papers concerned noise suppression for pneumatic powered diamond drills. All the papers are listed in the bibliography. A list of sources searched is given in Appendix D.

Summary of Data

As indicated above, the diesel engine literature is important, because it provides extremely good information on the engine as a noise source. It is doubtful that any work done under this study could equal this work. Reference 15 provides some insight into the sources of noise emitted from diesel engines. The following information is summarized from this reference as relevant at this time:

> It is generally considered that combustion forces are the greatest causes of engine noise. Because of the complexity of the combustion process, the resultant frequencies of the fundamentals and harmonics can often be treated as a continuous spectrum. Some advantage can be obtained from improving the combustion process, changing engine temperature and using different fuels. For instance, turbo-charging can reduce engine noise levels by approximately 2 - 3 dB. In addition to the combustion noise, the mechanical noise is also a significant noise source. Mechanical noise is caused by piston slap, timing gear engagement, valve seating, injector and pump forces, mass forces, bearing clearances, etc. Mechanical noise is responsible for most of the high frequency noise above 1000 Hz.

Reference 1 gives further insight into the exhaust system and the cooling system. It would appear that with respect to trucks, the cooling system is one of the major sources of sound production, while the exhaust system shell also radiates a considerable amount of noise. Much of the work reported in the above references, and others (see bibliography), would indicate that a considerable amount of work is being done in terms of general and close-fitting enclosures. General enclosures are enclosures which are more like a large box. Close fitting enclosures follow the engine contour as closely as possible. Close fitting enclosures require approximately a 15% increase in cooling system capacity to offset the loss of radiating area provided by the engine. Enclosures also increase potential fire hazard. In designing quiet systems, it is important to consider the exhaust pipe shell and the muffler shell. With a good muffler, it would appear that these noises exceed the noise of the exhaust itself.

The information obtained on pneumatic motors was supplemented with a discussion with a noted authority in the industry. See reference 12. To properly muffle an air motor, without losing power through increased back pressure, it is necessary to take care of the freezing problem. Air discharges from an air motor at a temperature of about -25°C. The recommended practice is to use a hose about 2" - 2-1/2" in diameter placed on the exhaust ports of the pneumatic motor of sufficient length to allow the air to warm up before it reaches the muffler. The hose should be bent as often as possible in order to cause any ice particles that would form, to become separated from the high velocity air stream. A gradual slope of the hose towards the muffler end is also beneficial in getting rid of oil and water particles that may be entrained in the airstream. Once the air has been sufficiently warmed, there are apparently a number of good mufflers that will do the job of silencing the exhaust of the motor. However, once the exhaust noise has been effectively controlled, there may be other noise sources which will appear, like the box within the box; that could also require further treatment.

One major problem with using a hose is that significant amounts of noise may escape through the hose walls, short-circuiting the muffler.

Reference 2 treats this problem directly for diamond drills. It would appear that even with a standard car muffler, reasonable results were achieved. It is unfortunate that the one test run with and without the head, appears somewhat conflicting in results. Figure 5, in Reference 2, indicates a total noise reduction with the head off of 2 dB. However, the figures on the graph indicate this is approximately 7 dB. If a reduction of 7 dB can be obtained by removing the head, it would indicate that the head is extremely noisy or that removing the load has a large effect on the sound produced by the motor.

A patent search was conducted on all phases of noise control as related to the project. All of the patents obtained however, were associated with pneumatic exhaust mufflers. While some of these are effective, the icing problem has not yet been adequately solved and it is necessary to pick a heat exchanger - muffler combination by trial and error which will not ice up in a particular application.

CHAPTER 5

AVAILABLE NOISE DATA FOR DIAMOND DRILLS

Sources of Information

As part of the survey, inquiries were also made about available sound level data. Since most of the diamond drills are either diesel powered surface rigs or pneumatic-powered underground rigs, sound level readings on these types of machines are the most readily available. Two major mining companies and one contractor were able to supply measurements. The M.A.P.A.O. were also able to supply data. As mentioned earlier, one paper, reference 2, also contained information of measurements on diamond drills.

General Noise Levels

While there are some variations, it would appear that diesel powered equipment generally has a noise level of about 105 dBA when operating in a plywood enclosure. Underground air powered equipment generally has a noise level of approximately 120 dBA.

Figures obtained from the contractor indicate that on one large surface drill, isolating the diesel in a separate room and using a direct drive hydraulic motor on the head can reduce sound levels by 10 dB. The limiting factor in this case is believed to be the integrity of the wall between the engine room and the drilling area.

Pneumatically powered equipment is extremely noisy. The general level is 120 dBA. The major mining company contacted indicated an L_{eq} of 113 dBA on two tests and 102 dBA on one test. These measurements used the dosimeter equipment mentioned earlier in this report. Similar measurements were obtained from the M.A.P.A.O. on surface mounted diesel equipment. This information indicated an L_{OSHA} of 104 - 108 dBA on various types of surface equipment.

Measurements for electric equipment running underground indicated a noise level of 100 dBA. This data is shown in Table 4.

TABLE 4

OCTAVE BAND ANALYSES ON DIAMOND DRILLS

DRILL		MEASUREMENT	OPERATING	dBA	dBL	dB AT INDICATED FREQUENCIES (Hz)									
TYPE (Power Unit)	ENVIRONS	LOCATION	CONDITION			31.5	63	125	250	500	1000	2000	4000	8000	16,000
1. Longyear 38 (Diesel)	17.5'x11.5'x7.5'Uninsulated Plywood Drill Shack	Operator Position	Drill Idling, No Load	93	95	79	87	89	86	83	90	87	80	70	-
				93	99.5	93	94	93	86	84.5	90	85	74	67	61
			Slow Run, No Load	97	100.5	80-82	90.5	97	93.5	89	93	89	79.5	72.5	66
			WOT*, No Load	106	108	86	91	90	100	99	103	102	98	93	-
				107	109.5	79-81	93-95	97-99	104	107	102	98	93.5	88	80
2. Longyear 38 (Diesel)	Canvas Drill Shack	Operator Position	Idling	94	101	85	93	98	88	-	-	-	-	-	-
			Slow Run	100	105	88	97	102	103	92	94	94	90	82	-
				102	108	88	96	98	103-106	93	96	96	-	-	-
			WOT	104	107	85	96	99	99	96	99	100	93	85	-
3. Boyles 17A (Diesel)	12'x14'x7' Uninsulated Plywood Shack	4 ft.from Water Pump	Pump only	93-94	98	90.5	88	90	92.5	89.5	88	85.5	84	84	82
		Operator Position	WOT	104	106.5	82	101	93**	96	98	100	98.5	92	87.5**	82
4. BBS (Pneumatic)	Underground, 15'wide Stope	Operator Position	WOT	115	125	85	98	99	110	114	-		-	-	-
5. Electric	*Underground	Operator Position	Unknown	100	103	90	90	84	90	93	94	95	92	87	81

*Measurement taken by a mining company

WGT = Wide open throttle
dBL = Linear Scale
** = Machine not steady for entire run

The one paper, Reference 2, on pneumatically powered drilling equipment indicated a 5 dBA improvement using an automotive muffler, reducing the level from approximately 108 dBA to 103 dBA. In the same reference figures are also shown running with and without the head. These, however, might not be representative since it is likely that the noise level would increase under part load conditions.

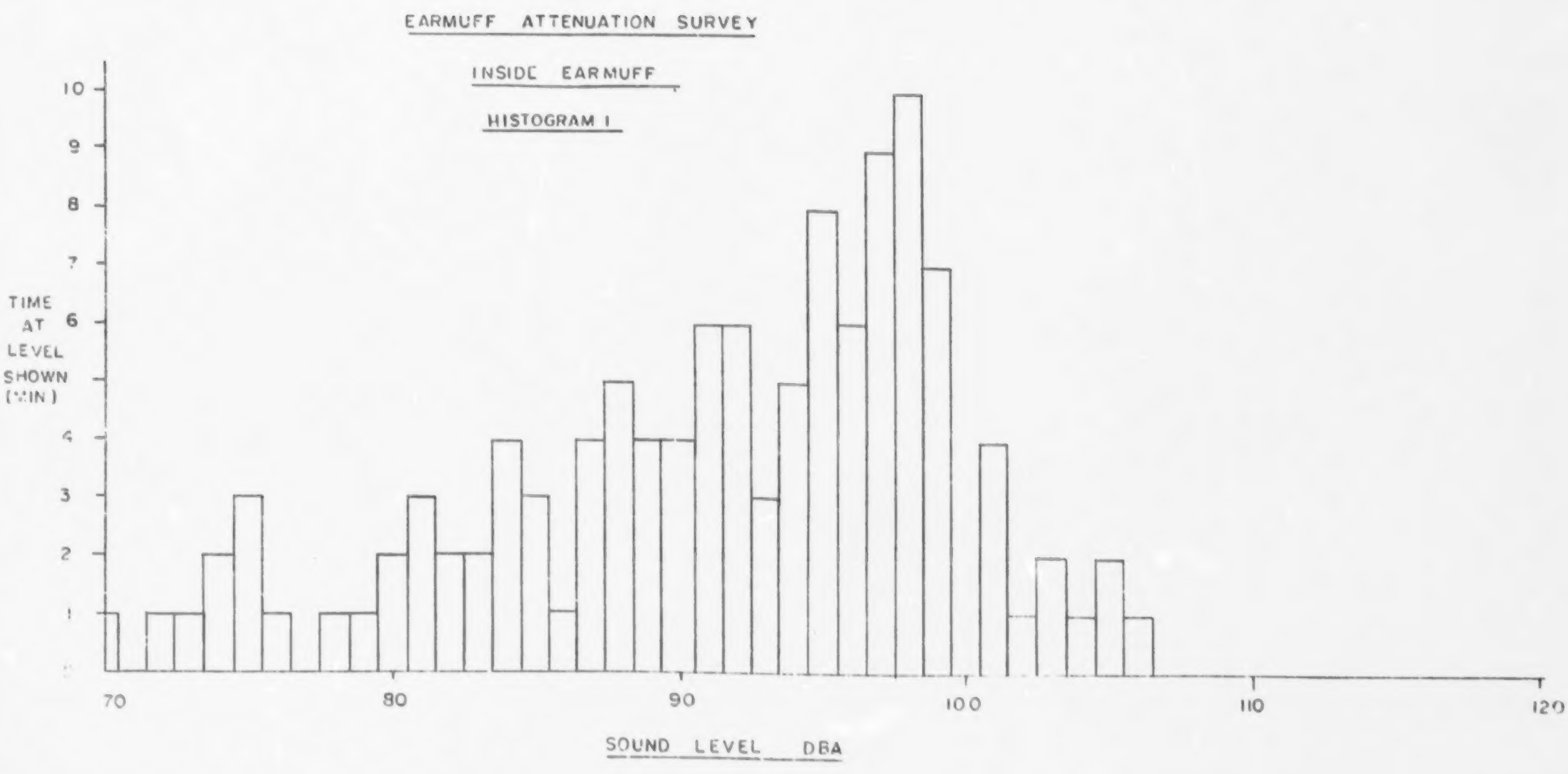
Agency Requirements

All of the provinces were contacted regarding noise level restrictions. The names of the people contacted, their office and addresses along with relevant data is provided in Appendix C.

Hearing Protection

As part of their normal research activity, Noranda has completed an earmuff attenuation survey. Histograms 1 and 2 show the results of this survey using sound level equipment both outside and inside the muff. From this and other information, Noranda is recommending that 15 dBA be used as the figure for attenuation with muffs and that an additional 5 dBA be added if both muffs and earplugs are used. These figures are generally additive, in other words if 85 dBA is allowed without any protection, then with muffs 100 dBA is an acceptable level and with both muffs and plugs 105 dBA is an acceptable level.

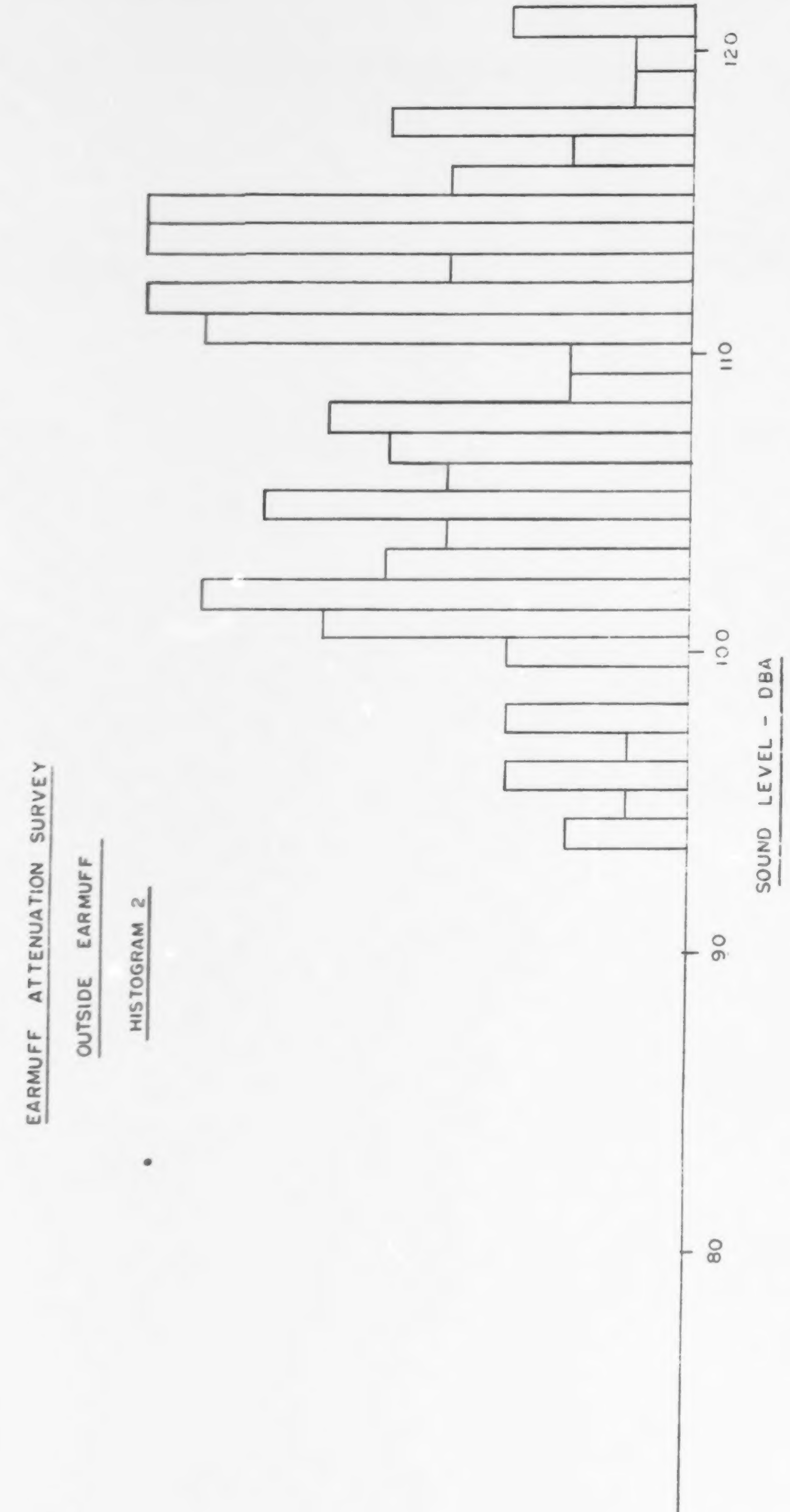
In explanation of the histograms, they are used in conjunction with equations (1) or (2) to establish an equivalent 8-hour dose. This is used to determine the effectiveness of the hearing protection.



EARMUFF ATTENUATION SURVEY

INSIDE EARMUFF

HISTOGRAM I



EARMUFF ATTENUATION SURVEY

OUTSIDE EARMUFF

HISTOGRAM 2

CHAPTER 6

MEASUREMENTS

Measurement Sites

It was not within the scope of this contract to complete an extensive measurement program. However, as part of the work, routine octave band analysis and two narrow band spectrum analyses were made. Sites were located in the Kirkland Lake and Noranda areas with both surface diesel rigs and underground pneumatic rigs covered. Unless specifically noted otherwise, the measurements were taken at or close to the operator's position at a height of 1.2 m, and in reverberant field.

Equipment Used

Measurements were made using both type 1 (± 1 dB) and type 2 (± 2 dB) meters with octave band filters attached. This equipment was calibrated prior to each use. Tape recordings of one surface rig and one underground rig were also obtained for later narrow band analysis. To complete the picture, measurements are also given for an electric rig as obtained from a major mining company. A typical octave band analysis is given for reference (Figure 3).

Results

The octave band data for 3 diesel powered surface rigs, one pneumatic powered underground rig and one electric powered underground rig, are summarized in Table 4. The data reveals that the acoustical energy is mostly concentrated in the 250 - 2000 Hertz octave bands, where the ear is most sensitive. Application of the A-weighting in these bands further indicates that the 1000 and 2000 Hertz bands, which are most likely to damage the human ear, also contain a good deal of the sound energy.

A narrow band analysis (400 lines from 0 to 10 kilohertz) was carried out on noise measured at the operator position of the diesel powered Boyles 17A drill operated above ground. A similar analysis was also carried out on noise measurements made near the drill engine, transmission and head. Matching of the spectral signatures of each close-up measurement to those obtained in the operator position suggests the peaks labelled in Figure 4 are the result of the indicated noise sources. It should be stressed that Figure 4 is a preliminary scan and that a more detailed analysis will be required to

TYPICAL OCTAVE BAND ANALYSIS OF THE SOUND PRODUCED BY A DIESEL-POWERED DRILL AT THE OPERATOR'S POSITION

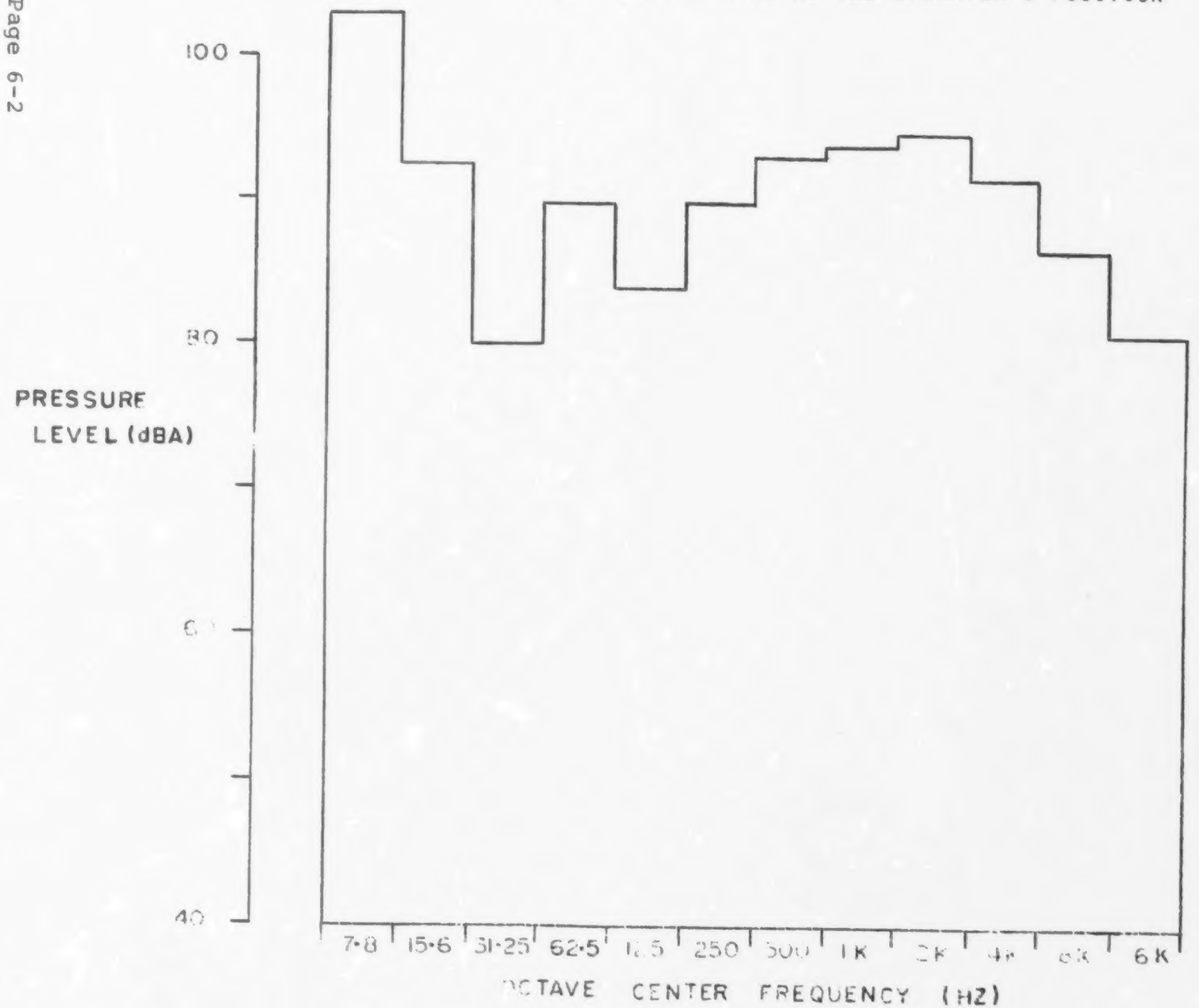


FIGURE 3

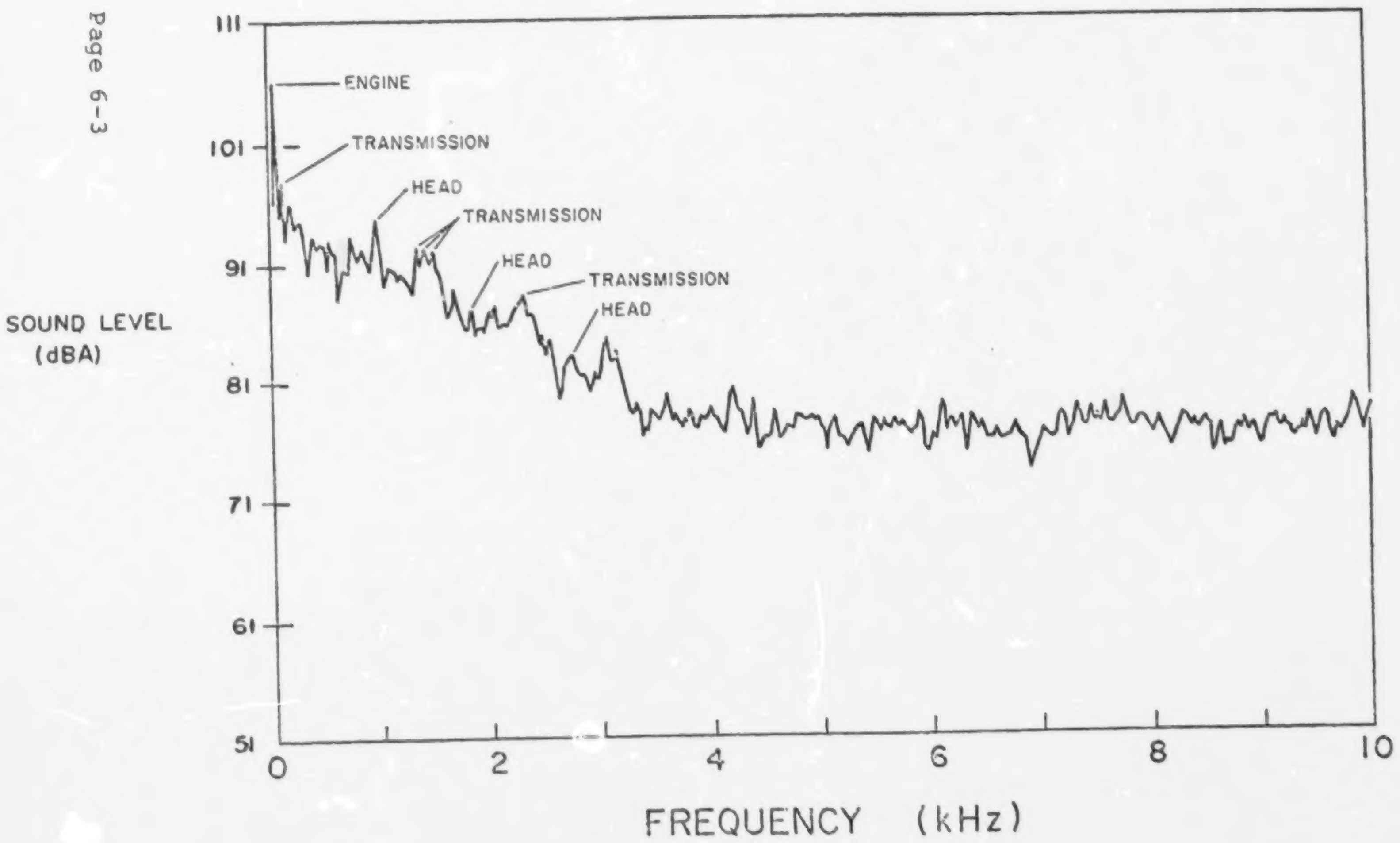


Figure 4 - NARROW BAND ANALYSIS ON BOYLES 17A

DIESEL POWERED DIAMOND DRILL

(OPERATING ON SURFACE)

positively identify all noise components. Figure 4 however, implies that in addition to the engine, noise control measures may also be required for the transmission and the head.

A similar spectrum was obtained on a Boyles pneumatically powered drill operating underground. Figure 5 shows the resulting plot of this information. If one adjusts for the different types of filtering, the spectral signature is quite similar to the one plotted in reference 12 which is reproduced in this report as figure 6. Note that the noise appears to be all motor tone or exhaust noise and that air-jet noise appears to be completely lacking for this installation. The first is close to a peak of 375 Hz to a motor RPM of approximately 3600 with 6 vanes. While this is probably a major cause of the noise, drill failure prevented confirmation of this.

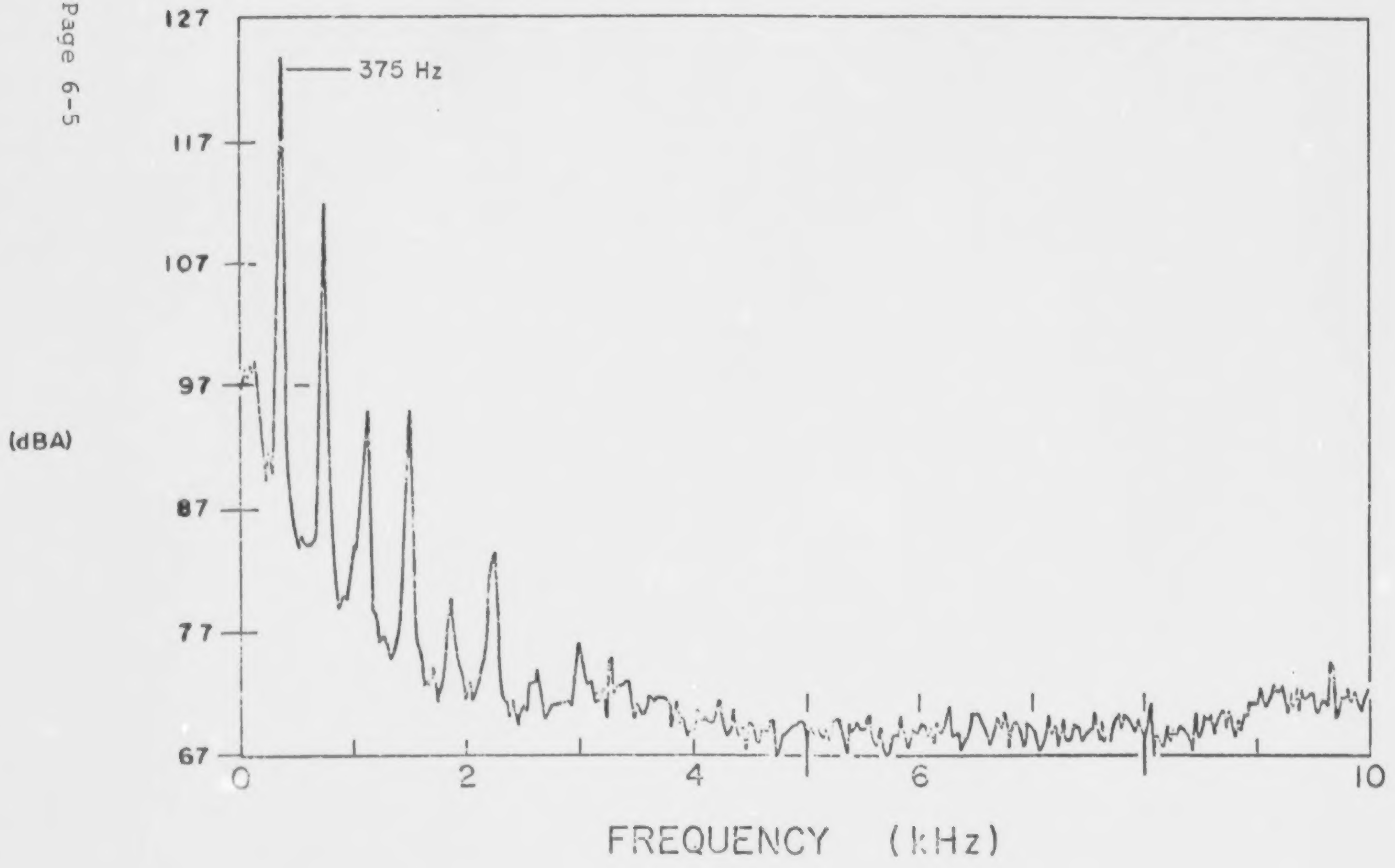


Figure 5 - NARROW BAND ANALYSIS ON BOYLES PNEUMATICALLY POWERED DIAMOND DRILL (OPERATING UNDERGROUND)

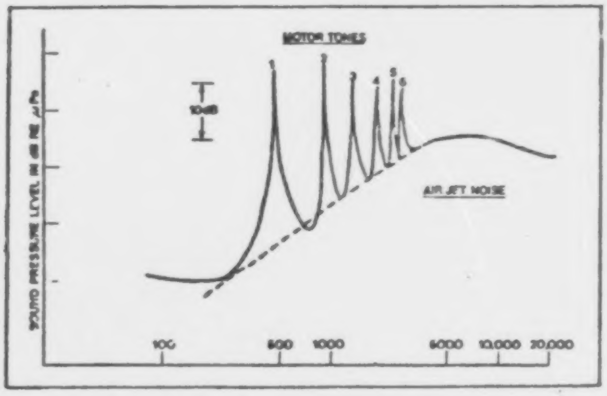


Figure 2. Air motor noise spectrum 1% B.W. wave analyzed microphone 1 meter from source.

Figure 6

(After Reference 12)

CHAPTER 7

RECOMMENDATIONS TO THE INDUSTRY

General Remarks

Only on rare occasions is the solution to a sound problem simple. The production of a quiet diamond drill is no exception. Even if the power sources were completely muffled, it is quite possible that other sources of noise may also be significant and prevent this one measure from substantially reducing the noise. It is known, for instance, that the straight cut bevel gear in some heads is extremely noisy. There are also a large number of methods which can be applied, all of which, if used correctly, will give good results; however they may not be applicable. One major drilling contractor indicated that he had spent considerable time screening off the engine only to find out that the drillers had cut holes in the screen, presumably to obtain the heat supplied by the engine. Another instance was reported of a fire resulting in a similar screen constructed to reduce engine noise. Regardless of what method is used, it will have to be compatible with the requirements of the industry.

Internal Combustion Engine Powered Equipment

Figure 7, a histogram reproduced from reference 15, is included on the following page. While this histogram was obtained outdoors and about 50 feet from a truck, it indicates the relative importance of various noises produced by the engine and its sub-components. An example of what a similar histogram for a diamond drill might look like in theory is shown in figure 8. From the literature, (reference 4 and figure 9 in this report), it is known that a diesel engine produces sound levels similar to those measured on diamond drills, however, if the engine could be eliminated, there still may be enough noise emanating from the sub-components such as the transmission, the head and other sources, rod rattle, etc., to cause noise levels well above the regulated requirements.

The first histogram also indicates the importance of isolating all of the engine sources and not just the exhaust or the engine itself. In other words, the cooling system, the exhaust system, the engine itself and the intake system all require sound treatment.

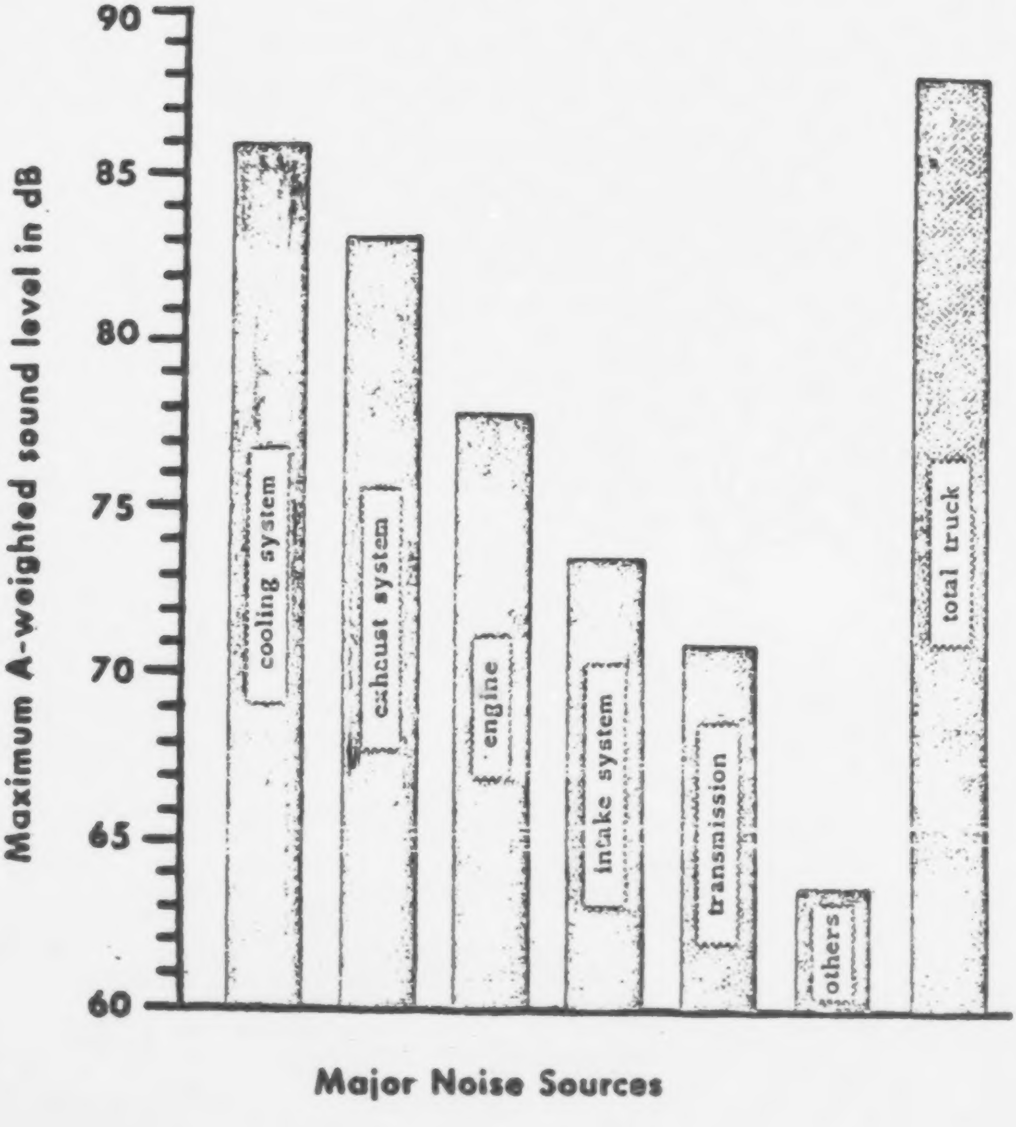


Figure 7

(After Reference 15)

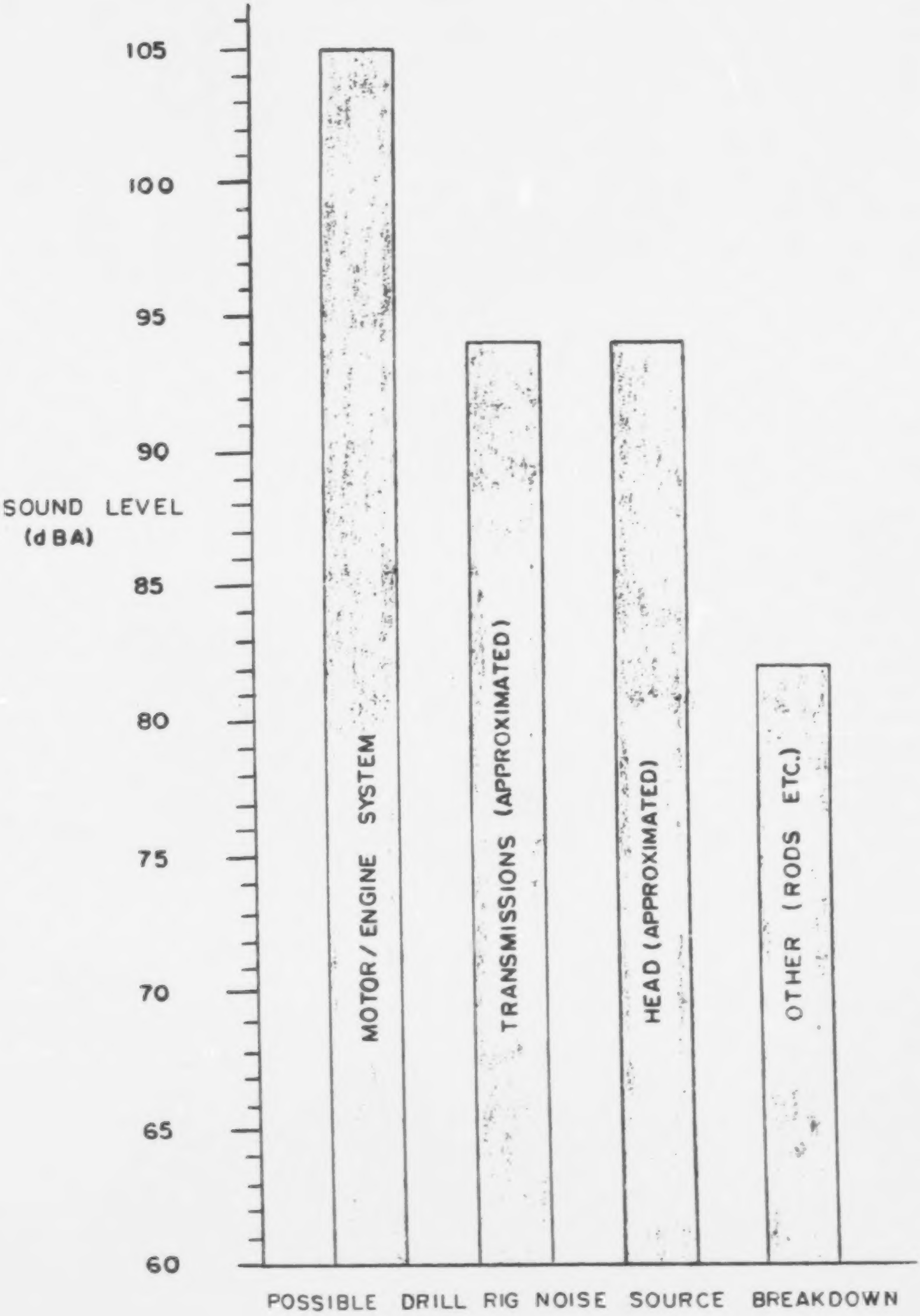

105
100
95
90
SOUND LEVEL (dBA)
85
80
75
70
65
60
MOTOR / ENGINE SYSTEM
TRANSMISSIONS (APPROXIMATED)
HEAD (APPROXIMATED)
OTHER (RODS ETC.)
POSSIBLE DRILL RIG NOISE SOURCE BREAKDOWN

FIGURE 8

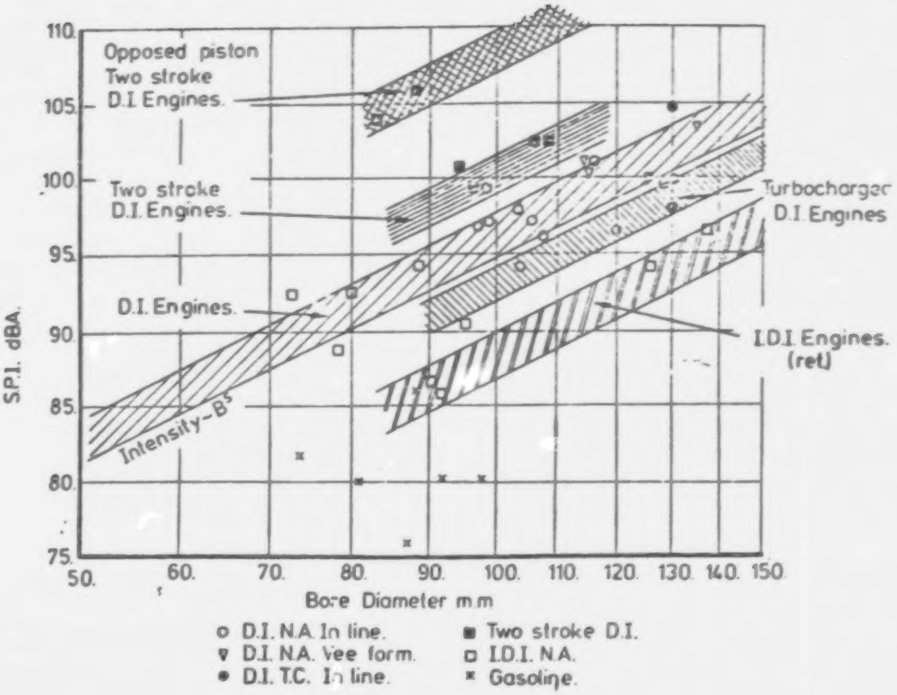


Fig. 15 - Relation between measured overall noise and bore size of engines in the various groups at 2000 revs/min

Note: D.I. Diesel Ignition
I.D.I. (Swirl Chamber)

Figure 9

(After Reference 4)

The sound treatment can be accomplished in several ways. Close fitting covers may be applied to the engine and the cooling system with the intake and exhaust system lagged to prevent noise from being transmitted from their surfaces. Vibration isolators would also be provided to prevent the noise from coming through the mounting points. Remote controls with tight fitting gaskets would be required to prevent the noise from getting out of the enclosure. The disadvantages of this method are that it would make this engine difficult to service. It also increases the potential fire hazard. The advantage is that the engine remains in its present location and providing it is done correctly, it would be possible to recover the heat from the engine, which is important during the wintertime operation of the surface drilling equipment. We question whether an effective enclosure could be designed which would be acceptable to the operators and robust enough to survive the physical abuse which it would incur.

Another solution would be to move the engine outside the drill shack. Power would then be transmitted to the drill by either a power takeoff shaft or a hydraulic or hydrostatic transmission. The engine would be sound-proofed using conventional type enclosures and intake and exhaust silencers. Remote controls would be required for the control of the engine. Waste heat from the engine would have to be ducted to the drill shack for warmth in wintertime. The water pump should also be moved to a separate enclosure.

Air Powered Equipment

It appears that pneumatic powered equipment would be less difficult to sound-proof than diesel powered equipment. The motor noise appears to be exclusively exhaust noise caused by vane pulsations with almost no jet noise at present. Reference 12 indicates that some improvement can be accomplished by re-designing the pneumatic motor. These changes can be done by re-designing the timing system and the exhaust porting system of the motor and if done carefully they do not result in any power loss. Reference 12 indicates that a reduction from 90 dBA to 84 dBA was accomplished by this method.

For existing rigs, the installation of a good muffler is probably a solution. However, for a muffler to work properly, it is absolutely necessary that the air be warmed up efficiently to prevent freezing of the moisture in the -25°C. exhaust temperatures. The use of 2 - 2-1/2" diameter hose to accomplish this function imposes a heavy penalty on portability and convenience and tends to short-circuit the muffler by allowing sound to escape through the hose. A heat exchanger utilizing the drill fluid could accomplish the same function in a much shorter and more compact package. Further noise reduction might also be achieved by using a deadening material or lagging around the motor housing and any gear train.

Drill Shack Improvement

The drill shack is generally a reverberant enclosure. Placing a simple durable sound-absorbing material on some of the walls of the drill shack could improve the noise level in the drill shack by approximately 5 dBA. The requirements placed upon the material, however, are substantial. It must not absorb the oil and water usually present during drilling and thus impose a fire hazard. It must also withstand impacts from the ends of drill rods and be easily cut to provide access to the drill should it be necessary to gain clearance for a rod or some other similar function.

Sealing Considerations

This subject is treated separately because, if its importance is not realized, then all benefit of soundproofing may be lost. Even a small hole will allow a considerable amount of noise to escape. Any sound-proofing must therefore be airtight. This imposes some severe restrictions on openings which will require good, well-designed gaskets and other points of access through the sound barrier. (See, for instance, L. H. Bell, "Fundamentals of Industrial Noise Control" 1973 Harmony Publications p 7.16).

Portability and Accessibility

It goes without saying that diamond drilling equipment must be portable. It must also be easily accessible for servicing. No benefit will be gained from enclosures which, after the first field servicing, are no longer soundproof. Generally, a driller will not put something back unless it has to go back or it falls back into place on its own.

Summary Table

Table 5 summarizes the major problem areas where acoustical treatment is necessary. Alternative control measures are discussed for each and our comments given. At this stage all of these comments and alternatives must be regarded as preliminary.

TABLE 5

SUMMARY TABLE

Problem	Possible Noise Control Alternatives	Comments
Diesel	Enclose	May be very hard to get an effective enclosure which will stand up.
	Move outside drill shack	Provision for remote control and remote radiator (for heating drill shack) required.
	Replace motor	Quiet enough motors not soon available. Expensive.
Pneumatic Motor	Exhaust Muffler	Warm the air to prevent icing.
Hydraulics	Acoustical Lagging	Effective, inexpensive, must be rugged.
	Quiet Components	Expensive unless only a few components need replacing.
Gears	Redesign gears	Practical in some cases.
	Enclose	May be able to upgrade existing housing.
Head	New Head	Must be certified quiet.
	Lag existing heads	Practical in some cases. Must be rugged.
Drill Shack Reverberation	Line with sound absorbing material	Must be rugged, not soak up oil or water.
Rod Chatter	Resilient rim for Standpipe	Difficult to enforce its use. Material selection may be a problem.
	Resilient sleeve inserted in standpipe	Difficult to enforce its use. Material selection may be a problem.

CHAPTER 8

ONGOING EFFORT

Noise Investigations

As indicated earlier in this report, there is little use in duplicating the work done in the automotive industry on diesel engine components. However, very little is known about the inherent noise of the drilling operation. For this reason, tests on drills under actual operating conditions but with various noise sources isolated, should be undertaken. These tests can only be done reliably under actual field conditions because operating conditions and maintenance have such a large influence on noise levels.

Design & Construction

Once the tests described above are completed, then noise reduction systems for both pneumatic powered and diesel powered rigs should be designed and constructed. This phase of the work should be done in co-operation with the diamond drill industry. It is suggested that the work be done by contractors well acquainted with the industry and well acquainted with noise control problems and set up with a sub-committee of the C.D.D.A. The sub-committee of the C.D.D.A. should consist of maintenance and field personnel from drilling companies. At each phase of the work, this committee should meet and discuss the proposed changes to ensure that the final result will conform to the requirements of the industry. This method has been used quite successfully in the past and provides useful results. It has the double advantage of merging field experience with good design practice while at the same time providing education for the field personnel.

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APPENDIX A

QUESTIONNAIRE

HEATHWOOD ENGINEERING ASSOCIATES LIMITED

Telex 067-82512 Box 190 Telephone (705) 567-3295

Kirkland Lake, Ontario, Canada P2N 3H7

HEATHWOOD

Dear Sir:

As part of a study of noise in the diamond drilling industry sponsored by the Canadian government, we are conducting a survey of diamond drilling companies.

We have done our best to make the attached questionnaire fast and straightforward to answer. Could you please take 15 or 20 minutes right now to complete the attached questionnaire, as we have only a limited time to complete this survey, and your answers are very important to its success.

Please return the questionnaire to us in the stamped self-addressed envelope enclosed. If you do not use diamond drills, could you please indicate so on the questionnaire and return it to us.

This survey is being used to help us determine the present state of the diamond drilling industry with respect to noise and noise control. Our results will be written up in a report which will be available from the CDDA or CANMET.

We will endeavour to present the information from this survey without identifying particular companies. However, you should not include with your answers anything which you consider to be of a proprietary nature.

Thank you for your help on this work.

Yours very truly,

T. Kelsall
Acoustics & Noise Control

TK/bb
Encl.

CANADIAN DIAMOND DRILLING NOISE QUESTIONNAIRE

1. What types of diamond drills do you have?

DRILL	MANUFACTURER	HOLE SIZE (E,A,B,N...)	NUMBER OF EACH	TYPE OF ENGINE (diesel,gas,pneumatic electric,other) (2,4,6, 8 cylinder, 2 or 4 cycle)	TYPE OF DRIVE (mechanical, hydraulic)	ENGINE MANUFACTURER	EXHAUST SILENCER (muffler,pneu- matic exhaust silencer)
1							
2							
3							
4							
5							

2. Please describe any problems you have had with exhaust silencers or mufflers and any modifications you have made.

3. How close is the operator:

	DRILL - NUMBERED AS IN QUESTION #1				
	1	2	3	4	5
a) to the drill?					
b) to the engine?					
c) to the exhaust?					
d) to the water pump?					

4. What type of water pump is used?

DRILL	MANUFACTURER	HP	NUMBER	TYPE	ENGINE (Check One)				
					DIESEL	GAS	PNEUM.	ELECTRIC	OTHER
1.									
2.									
3.									
4.									
5.									

5. What type of wire line hoist drive is used (if any)?

					ENGINE (Check One)				
DRILL	MANUFACTURER	HP	NUMBER	TYPE	DIESEL	GAS	PNEUM.	ELECTRIC	OTHER
1.									
2.									
3.									
4.									
5.									

6. Are the drills used:

	DRILL				
	1.	2.	3.	4.	5.
a) underground?					
b) in a shed of wood?					
metal?					
canvas?					
c) in a partial shelter?					

7. If the drill is in an enclosed space, are the walls lined with sound absorbing material such as fiberglass batts?

YES ________ DESCRIBE ____________________

NO ________

8. Are any other noise control measures employed? (Please use back of page if necessary)

____

____

____

9. Does the company supply hearing protection?

Ear muff protectors? ________ Ear plugs? ________ Nothing? ________

If so, what percent of the operators use them? ____ %

What reasons, if any, are given for not using them?

____

____

10. Have you ever had any complaints about noise:

	YES	HOW MANY	NO
a) from operators?			
b) from nearby habitations?			
c) from nearby workplace?			
Others? ________			

11. Have you ever had any compensation claims for worker hearing loss?

Yes ________ How many? ________ No ________

12. Are you subject to any government regulations concerning noise?

Yes ________ No ________ Enforced By? ________________________________

13. Have you ever been contacted concerning these regulations?

Yes ________ No ________

14. Do they have regular inspections?

Yes ________ How Often? ________________________

No ________

Please check the name and address below and change if necessary.

THANK YOU!

APPENDIX B

SURVEY RESULTS

The answers received for each question, denoted Q1, Q2, etc., are summarized below. Please note that totals from different tabulations do not agree since some respondents left certain sections of the questionnaire blank.

Q 1. Breakdown of drill manufacturers:

Out of 423 Drills:

Boyles-Dresser	64%	
Longyear	22%	
J.K. Smit	6%	
Acker	<1%	8%
Atlas Copco	<1%	
St. Lambert	<1%	
Wesdrill	<1%	
Morissette	<1%	
Becker	<1%	
Reich	<1%	
Mobile	<1%	
Midway	<1%	
Joy	<1%	
Chicago Pneumatic	<1%	
Homemade	<1%	

Q 2. Use of mufflers:

Diesel:	82%	(293 drills)
Pneumatic:	67%	(85 drills)
Gas:	70%	(10 drills)

Generally drillers use a flexible exhaust hose to remove fumes from drill areas.

Drillers expressed dissatisfaction with the performance of mufflers, i.e. they did not solve the problem.

Q 3. Average distances from operator

	Surface	Underground
to drill	1.9'	2.5'
to engine	4.6'	3.0' Pneumatic, Electric 19.2' Diesel
to exhaust	7.2'	32' Pneumatic 16.8' Diesel
to water pump	7.7'	8.2'

Q 6. Where drills are used.(survey favours drilling companies over mining companies who own their own drills.)

Surface

In a wood shed:	207
In a canvas shed:	70
In a partial shelter:	25
Other:	10
Subtotal	312
Underground:	113
TOTAL:	425

Q 7. No interior acoustical treatment is used, even though 92% are in a reverberant environment.

Q 8. Other than hearing protection, mufflers and flexible exhaust hose, no other noise control measures are reported.

Q 9. Use of hearing protection:

All companies reporting supply ear muff protectors and 10/18* supply ear plugs also.

Respondents' estimates of the use of hearing protection give average figures of:

Underground: 100%

Surface: 72%

Mixed: 76%

Reasons given for not using hearing protection:

- Inconvenience
- Discomfort
- Cannot be bothered
- Cannot get used to them
- Do not realize importance
- Painful with glasses
- Change sound of drill
- Allergic to ear plugs

* (In explanation 10 out of 18)

Q 10. Complaints to drilling companies:

Complaints from operators:	8/19
Complaints from nearby habitations:	6/21
Complaints from nearby workplaces:	5/19

Q 11. Workmens compensation claims: companies out of

Jurisdiction	Number of Companies	
	Total	With Claims
Ontario	7	4
Quebec	5	3
British Columbia	3	2
Manitoba	1	-
Newfoundland	1	0
Northwest Territories	-	0
U.S.A.	2	0

Q 12. Knowledge of regulations:

16/20	Know they are subjected to noise regulations.
13/20	Know the agency enforcing the regulations.
6/20	Have been contacted concerning noise regulations.
9/20	Are regularly inspected.

DRILLS AVAILABLE

BOYLES DRESSER

DRILL	HOLES AND DIMENSIONS	HP	MOTOR	RPM	DRIVE (RPM)
X-ray	RW, EW, AW, BW (75 - 250') L:25", W:28", H:35" 240 lb	9	4 cyc. Gas	3600	Bevel Gear (720-1440 RPM and 360 - 720 RPM)
		11	Air	3300	
BBS-15	AWL, BWL, NWL HWL, AW, BW, NW, HW (500 - 1500') L:78", W:41", H:68" 2300 lb	37	Wisconsin VG4D Gas	2400	Bevel Gears (60 - 2000, 30 - 2000, 30 - 1500)
		26	Deutz Diesel F2L912	2300	
		29	Hatz Z108	2300	
BBS-15 UG	AWL, BWL, NWL HWL, AW, BW, NW, HW (500 - 1500') L:78", W:41", H:68" 2300 lb	20	Boyles BBU-2 Twin Cyl. Air Motor	1000	Bevel Gears (60 - 2000, 30 - 2000, 30 - 1500)
		25	TEFC Electric	1800	
		30	TEFC Electric	1800	
BBS-25	AWL, BWL, NWL, HWL, AW, BW, NW, HW (900 - 2500') L:105", W:46", H:88" 2850 lb	51	Ford 172 Gas	2800	Bevel Gears (60 - 2000, 40 - 1500, 30 - 1500)
		64	Ford 2711 E Diesel	2500	
		44	Deutz F3L912 Diesel	2300	
		43	Hatz D108 Diesel	2300	
		35	GM2-53 Diesel	1800	
		47	Ford 172 Diesel	2400	
BBS-25 UGE	"	40	TEFC Electric	1800	Bevel Gears (60 - 2000, 40 - 1500, 30 - 1500)

BOYLES DRESSER (Cont'd)

DRILL	HOLES AND DIMENSIONS	HP	MOTOR	RPM	DRIVE (RPM)
BBS-37	AWL, BWL, NWL, HWL, AW, BW, NW, HW (1350 - 3700') L:105", W:46", H:88" 5400 lb	84	Ford 240 Gas	2800	Bevel Gears (60 - 2000, 40 - 1500)
		64	Ford 2711 E Diesel	2500	
		58	Deutz Diesel F4L912	2200	
		58	Hatz V108 Diesel	2300	
		64	GM3-53 Diesel	2200	
BBS-37 UG	"	2 X 20	2:BBU-2 Twin Cyl. Air Motors	1000	"
BBS-56	AWL, BWL, NWL, HWL, AW, BW, NW,HW (2100 - 5650') L:117", W:46", H:95" 6000 lb	101	Ford 300 Gas	2800	Bevel Gears (30 - 1200, 30 - 1500)
		90	Ford 2713 E Diesel	2500	
		88	Deutz Diesel F6L912	2500	
		87	GM4-53 Diesel	2200	
Bazooka	BW, EW (100 - 150') 170 lb	16	Boyles BVB-6 Vanetype Air Motor	3000	Direct
VAG	AW (510') 485 lb	27	Boyles BVRG-94P Vanetype Air Motor	3600	(300 - 3600) Direct
VEG VEGR VEGRC	EW (700') 376 lb	27	Boyles BVRG-94P Vanetype Air Motor	3600	(300 - 3600) Direct

BOYLES DRESSER (Cont'd)

DRILL	HOLES AND DIMENSIONS	HP	MOTOR	RPM	DRIVE (RPM)
JV, JVR JVRC	EW (700') 437 lb	27	Boyles 2 Cyl. V Type Piston Air Motor	2000	Bevel Gears (1430 - 2600)
JVA	AW (510')	27	Boyles 2 Cyl. V Type Piston Air Motor	2000	Bevel Gears (1430 - 2000)
BBU2	EW, AW (1400 - 1800')	20	Boyles 2 Cyl. V Type Piston Air Motor	1000	Bevel Gears (714 - 1200)

LONGYEAR

DRILL	HOLES AND DIMENSIONS	HP	MOTOR	RPM	DRIVE (RPM)
24 Std.	EW:890' AW:675' L:67", W:36" H:54" 1170 lb	12	Wisconsin Gas	2200	Bevel Gears (224 - 2161)
		20	Deutz Diesel	2200	
24 Wolverine and 24 Std.	EW:890' AW:675' L:47", W:25" H:58" 780 lb	20	Ingersoll-Rand Air-90 psi	2000	Bevel Gears (203 - 1964) (183 - 1768)
		10	Louis Allis Electric	1800	
34	AQ, BQ, NQ, HQ wireline, AW, BW, NW, HW 600 - 1700' L:103", W:42", H:57" 3300 lb	31*	Wisconsin 4 Cyl.Gas VG4D	2200	(10 - 1350) (14 - 1850)
		38*	Ford 172 4 Cyl. Diesel	2200	
		40*	Deutz F3L-912 3 Cyl. Diesel	2200	
38	Rods as above 1100 - 3100" L:103", W:42", H:57" 3300 lb	45*	Ford Gas-172	2200	(25 - 1350) (35 - 1850)
		42*	Ford 4 Cyl. Diesel-172	2200	
		54*	Deutz F4L-912 4 Cyl. Diesel	2200	
44	Rods as above 1600 - 4350' L:108", W:46", H:66" 4850 lb	60	GMC 3-53 Diesel VG4D 4-53 Diesel	2200 2200	(211 - 1320)
		60	Deutz F5L-912 Diesel	2200	
HC-150	AQ, BCQ, NCQ, HCQ AW, BW, NW, HW 550 - 1500' L:118", W:64", H:82" 4685 lb	65	GMC-53 Diesel	2200	(430 - 1620) Hydrostatic
		65	Deutz F4L-912 Diesel	2200	

* 15% below manufacturer's rating.

WESDRILL

DRILL	HOLES AND DIMENSIONS	HP	MOTOR	RPM	DRIVE (RPM)
60	N(3000') (9000 lb)	120	Ford Diesel 380 High Ouput	2500	Bevel Gear (15 - 1800)

J.K. SMIT

DRILL	HOLES AND DIMENSIONS	HP	MOTOR	RPM	DRIVE (RPM)
Winkie	EX, EXT, IEX, AX, AXT, IAX, BX 150 - 475' L:21", W:21" 75 lb and 90 lb stand	10	Gas 2 Cyl. Air-Vane Type	8400	2 Speed (2800, 1200 maximum RPM)
JKS-25	XRP, IEX 100 - 150' 48 lb 205 lb with stand	8.6	Multivane Air Motor 100 psi	3000	3:1 Transmission
JKS-300	A,B -wireline 750 - 1000' L:72", W:35", H:45" 822 lb-power and 730 lb-mast	40	Gas Diesel Air Electric (remote)	2600 to 3000	Hydraulic (50 - 1700)

ACKER

(Rarely used in Canada, 15% duty)

DRILL	HOLES AND DIMENSIONS	HP	MOTOR	RPM	DRIVE (RPM)
Ace	E, A, AW 315 - 800' L:72", W:40", H:63" 1450 lb	14.4	Wisconsin TJD Gas Engine	3200	Spiral Bevel Gear (204 - 1302)
		19.8	Diesel	3000	
		7.5	Electric	1750	
		10.0	Air	Var.	
Mountaineer	AW, AQ, BW, BQ, NW, NQ, HW, HQ 1300 - 4500'	58	Ford D172 Gas Engine	2800	Spiral Bevel (61 - 1484)
	L:91", W:42", H:60½" 3300 lb	58	Deutz F4L912 Diesel	2300	
		44	Ford DF192 Diesel	2400	
Core Max	AQ - PQ 900 - 3100" L:31", W:8", H:32" with mast 8500 lb	73	Deutz F5L912 Diesel	2300	Hydraulic Motor

APPENDIX C

AGENCY REQUIREMENTS

APPENDIX C

PROVINCE	GOVERNMENT OFFICE	ADDRESS & TELEPHONE	REFERENCE
1. Alberta	Occupational Hygiene Branch, Occupational Health & Safety Div., Alberta Labour.	9820-106 Street, Edmonton, Alberta T5K 2J6	Mr. Jene Vng, Resp. 403/427-2687 (Garry J. Fink, C.I.N.J.)
2. Nova Scotia	Division of Occupational Health, Dept. of Health	P.O. Box 488, Halifax, Nova Scotia B3J 2R8	Mr. T.A. Mejzner, P.Eng., Dr. Hedges, Resp. 902/424-6980
3. British Columbia	Worker Compensation Board, Industrial Health & Safety	5255 Heater St., Vancouver, B.C. V5Z 3L8	Mr. Mike Hewitt, Head, 403/873-7468
"	Ministry of Mines & Petroleum Resources, Ministry of Energy	103,2747 East Hastings St., Vancouver, B.C. V5K 1Z8	Dr. Sam Alias, Resp. 604/254-7171
4. Northwest Territories	Northwest Territories Mining Safety Ordinance. Indian & Northern Affairs	Box 1500, Yellowknife, N.W.T. X1A 2R8	M.L. Brown, Resp., 403/873-7468
5. Saskatchewan	Dept. of Labour, Occupational Health & Safety Div.	1150 Rose Street, Regina, Saskatchewan S4P 3V7	Mr. Tom Keith, Resp. Occ. Health
6. Quebec	Mines et carrieres, Hygiene au travail	Quebec, Quebec.	Mr. Tanguay 418/643-4453
"	Ministere des Affaires Municipales, Section de la lutte anti-bruit	9310 Boul. St. Laurent, Montreal, Quebec. H2N 1N4	Mr. Aumont, Chief, 514-873-5874
7. Yukon	Yukon Territories Dept., Occ. Health & Safety Div.	Occupational Health & Safety, Box 2703, Whitehorse, Yukon	Accident Prevention Office, Gary McLaughlin, Resp. 403-667-5450

PROVINCE	GOVERNMENT OFFICE	ADDRESS & TELEPHONE	REFERENCE
8. Ontario	Mining Health & Safety Branch, Ministry of Labour	400 University Ave., Toronto, Ontario. M7A 1W3	Mr. Nelson, Resp., Mr. Sam Bell 416/965-4066
9. Manitoba	Occ. Health Safety, Dept. of Labour	Resources & Environmental Man. Bldg. 2, Box 7, 139 Toxedo Ave., Winnipeg, Manitoba.	Mr. Cam Younger, Resp., 204/944-2602
10. Newfoundland	Occ. Health & Safety, Dept. of Labour & Manpower	Box 9000, Philips Place Bldg., Elisabeth Ave. E., St. John's, Nfld.	William J. Louch, Ph.d. Industrial Hygienist, 709/737-2674 or 2691
11. Prince Edward Island	Worker Compensation Board	Box 757, Charlottetown,P.E.I. C1A 7L7	Mr. G. Muise, Indust. Safety Supervisor, 902/894-8555
12. New Brunswick	Mineral Resources Branch, Dept. of Natural Resources	Box 6000, Fredericton, N.B. E3B 5H1	R.W. Warren, Resp. 506/453-3706

	NOVA SCOTIA		NEW BRUNSWICK	
	Existing 1979	Proposed (None)	Existing 1978	Proposed (none)
1. Allowable Noise Level(s) (dBA - hours)	80 dBA - 16 hours 85 dBA - 8 90 - 4 95 - 2 100 - 1 105 - .5 110 - .25 115 - .125		87 to 90 - 8 hrs 90 to 92 - 6 92 to 95 - 4 95 to 97 - 3 97 to 100- 2 100 to 102-1.5 102 to 105- .5 105 to 110- .25 110 to 115- 0	
2. Maximum allowable dBA, without hearing protection	115 dBA		115	
3. Action required if allowable levels exceeded (in order specified)			Employer to reduce exposure time. Hearing protection. Posted sign.	
4. Audiometric Testing Mandatory (Under what conditions)	No, but if noise higher than TLV levels audio test should be applied		No	
5. Impact/Impulse Noise Criteria (dB Linear Peak -No. of Impacts) *	140 dBI - 100 times 130 - 1000 120 - 10,000		140 dbI - 100 times 130 - 1000 120 -10,000	
6. Special				

* period of 24 hrs.

	QUEBEC		ONTARIO	
	Existing 1972	Proposed (1979)	Existing	Proposed (Feb.'80)
1. Allowable Noise Level(s) (dBA - hours)	90 dBA - 8 hrs 92 dBA - 6 95 - 4 98 - 3 100 - 2 105 - 1 110 - .5 115 - 0	See copy of Gazette Officielle du Quebec 19 Decembre, 1979. P 7850	90 dBA - 8 hrs 92 6 95 - 4 97 - 3 100 - 2 102 - 1.5 105 - 1.0 110 - .5 115 - .25 Over 115- 0	Draft--- Publication early Feb. '80
2. Maximum Allowable dBA, without hearing protection	115		115	
3. Action required if allowable levels exceeded (in order specified)	-Isolation of noise source. -Limitation of intensity and duration. -Isolate the worker.		Reduce sound level <90 dBA Duration of exposure set with 1, above. Hearing protection	
4. Audiometric Testing Mandatory? (Under what conditions)	If exceeds 90-92 dBA for 8 hrs 92-95 dBA for 4 hrs 102 dBA upper limit		90 dBA recommended Pre-employment & pre-placement audiometric test Audio test (annual)	
5. Impact/Impulse Noise Criteria (dB Linear Peak -No. of Impacts)	No		140 dBI	
6. Special				

	PRINCE EDWARD ISLAND		M A N I T O B A	
	Existing	Proposed	Existing	Proposed (None)
1. Allowable Noise Level (s) (dBA - hours)	Industrial Safety Regulations Revised Statutes of P.E.I. 1974 Section 5.8 and 5.9		80 dBA - 16 hrs 85 - 8 90 - 4 95 - 2 100 - 1 105 - 0.5 110 - 0.25 115 - 0.125	
2. Maximum allowable dBA, without hearing protection			115 dBA	
3. Action required if allowable levels exceeded (in order specified)			None mentioned	
4. Audiometric Testing Mandatory? (Under what conditions)			No Suggested if workers are exposed to noise at or above TLV level.	
5. Impact/Impulse Noise criteria (dB Linear Peak - No. of Impacts)			140 dBI - 100 times 130 1000 120 - 10,000	
6. Special				

	SASKATCHEWAN		YUKON	
	Existing 1972	Proposed (Mar.'80)	Existing 1976	Proposed (3rd draft)
1. Allowable Noise Level(s) (dBA-hours)	90 dBA -current criteria	80-81-(16) 96-97(1.5) 82-83-(12) 98-99(1.0) 84-85-(10) 100-101(.75) 86-87-(8) 102-103(.5) 88-89(6) 104-105(.35) 90-91(4) 106-107(.250) 92-93(3) 108-109(.125) 94-95(2) 110+ (0)	90 - 8 hrs 92 6 95 4 97 3 100 2 102 1.5 105 1.0 110 0.5 115 0.25	85 - 8 hrs 90 - 4 95 - 2 100 - 1 105 - 0.5 110 - 0.25 115 - 0.125
2. Maximum allowable dBA, without hearing protection	Not indicated	110	115 dBA	85 dBA/8 hrs.
3. Action required if allowable levels exceeded (in order specified)	Employer should reduce the noise, isolate worker or provide hearing protection	Sign displaying the range of noise measured. Hearing protection.	Protective equipment	Institute engineering controls or obtain an independent acoustical evaluation.
4. Audiometric Testing Mandatory? (Under what conditions)	Nil	Nil	Not mentioned	Yes Over conditions in 1, above.
5. Impact/Impulse Noise criteria (dB Linear Peak - No. of Impacts)	Nil	Nil	Not mentioned	135 dBI/8 hrs.
6. Special	Nil	Nil	Nil	Nil

	ALBERTA		NEWFOUNDLAND	
	Existing	Proposed (1978)	Existing 1979	Proposed
1. Allowable Noise Level(s) (dBA - hours)	80 dBA - 16 hrs 85 - 8 90 - 4 95 - 2 100 - 1 105 - .5 110 - .25 115 - .125 or less	85 - 8 or more 90 - 4 95 - 2 100 - 1 105 - .5 110 - .25 115 - .125	80 - 16 85 - 8 90 - 4 95 - 2 100 - 1 105 - .5 110 - .25 115 - .125	
2. Maximum allowable dBA, without hearing protection	115 dBA	115 dBA	115 dBA	
3. Action required if allowable levels exceeded (in order specified)	Appropriate measures to suppress noise or isolate workers Protection equipment	Engineering controls Obtain independent acoustical consultant's evaluation	Employee should reduce noise to acceptable level. Personal protection	
4. Audiometric Testing Mandatory? (Under what conditions)	Yes High noise level? Request by Provincial Board of Health	Yes Over permitted exposure shown at 1 above	Not specified	
5. Impact/Impulse Noise Criteria (dB Linear Peak - No. of Impacts)	140 dB fast response.	135 dBI - 100 times 125 - 1000 115 - 10,000 Maximum allowable 135 dBI	140 - 100 times 130 - 1000 120 - 10,000 Maximum allowable 140 dBI	
6. Special Hearing Protector	Nil	85-95 Class C* 96-105 Class B 106 up Class A		

*Type of hearing protection as outlined by C.S.A.

	BRITISH COLUMBIA		NORTHWEST TERRITORIES	
	Existing	Proposed (1/10/79)	Existing	Proposed
1. Allowable Noise Level(s) (dBA - hours)	87 - 16 90 - 8	87 - 16 90 - 8 93 - 4 96 - 2 99 - 1 102 - 0.5 105 - 0.25 +105 - 0	90 - 8 92 - 6 95 - 4 97 - 3 100 - 2 102 - 1.5 105 - 1 110 - 0.5 115 - 0.25	Nil
2. Maximum allowable dBA, without hearing protection	?	105 dBA	115 dBA	Nil
3. Action required if allowable levels exceeded (In order specified)	Appropriate measure to reduce noise intensity	1-Engineering Controls 2-Hearing protector 3-Follow worker's exposure. Steady state permissible level.	No exposure without suitable protective equipment	Nil
4. Audiometric Testing Mandatory? (Under what conditions)	Yes Over 85 dBA steady state or impact noise at 5 above	Yes 85 dBA steady 8 hrs or impact noise at 5 above	No	Nil
5. Impact/Impulse Noise Criteria (dB Linear Peak -No. of Impacts)	dBI 140 - 0 139 -112 136 -225 133 -450 130 -900 I/24 hrs 127 -1800 124 -3600 121 -7200 118-14400	dBI +135 - 0 135 - 90 134 -112 131 -225 128 -450 I/24 hrs 125 - 900 122 -1800 119 -3600 116 -7200 113-14400	No	Nil
6. Special Hearing Protector	85-95dBA class C 96-99dBA class B	85-95 dBA - class C 96-105 dBA- class B 106-115 dBA- class A	No	Nil

I/24 = total number of impacts over 24 hr. period.

APPENDIX D

LITERATURE SEARCH SOURCES

LITERATURE SEARCH SOURCES

Computer Search

List of Files Searched

1 - W.P.I (World Patents Index)
2 - F.E.D.E.X. (Federal Register Index)
3 - E.P.B. (Environmental Periodical Bibliography)
4 - Conference Papers Index - 1973-79
5 - Compendex (Engineering Index)
6 - Informatic (French - Canada)
7 - N.T.I.S. (National Technical Information Service)

Search of Mining Journals (1970-1980)

- Environmental Health
- Australian Institute of Mining & Metallurgical
- Australian Mining
- C.I.M. Bulletin
- Engineering and Mining Journal
- Environmental Science and Technology
- Canadian Mining Journal
- Engineering Digest (3-4 years back)
- Institute of Mining and Metallurgy (I.M.M.)
- Machine Design
- Mining Congress Journal
- Mining Engineering
- Mining Equipment International
- Mine Safety and Health
- Mining Journal
- Mining Magazine
- National Safety News
- Western Miner
- World Mining
- American Industrial Hygiene Association Journal
- South Africa Institute of Mining and Metallurgy Journal
- United States Bureau of Mines (Dept. of Interior)

Search of Noise Literature

- Noisexpo Proceedings (1973-1979)
- Inter-Noise Proceedings (1972-1978)

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VOL. 5 Report 5

Heathwood Engineering Associates

E. P. Smith, P. E. Davis and R. Cyr

Diamond drill noise study phase II

CANMET contract No. OSQ80-00096

Rep. No. 0-9044 (1980)

DIAMOND DRILL NOISE STUDY

PREPARED FOR THE

DEPARTMENT OF ENERGY MINES & RESOURCES

CANMET

MINING RESEARCH LABORATORIES

PHASE II

BY

E P SMITH, P ENG

&

P E DAVIS, P ENG

IN ASSOCIATION WITH

NORANDA RESEARCH

R CYR, P ENG

RÉSUMÉ

Le présent rapport traite de la deuxième étape d'un programme en plusieurs parties visant à réduire l'intensité du bruit produit par les perforatrices au diamant. Les travaux accomplis ont consisté à définir les composantes de l'intensité du bruit des équipements utilisés en mine à ciel ouvert, d'analyser certaines techniques classiques et de concevoir un boîtier pour moteur.

En général, le bruit provient de quatre sources en parts égales, soit du moteur, de la pompe à eau, de la transmission et de la poupée porte-broche.

Un boîtier pour moteur a été conçu pour réduire le bruit du moteur à un niveau acceptable. D'autres travaux devront être accomplis pour trouver des solutions au bruit produit par les trois autres sources. Lorsque ces travaux seront terminés, le programme devra être repris en entier pour les perforatrices en mine souterraine.

FOREWORD

FORWARD

A number of people contributed to the success of this part of the project. Morissette Diamond Drilling provided assistance with the Hatz diesel engine. Mario Gauthier and his staff at the Northern College drilling school provided both the equipment for and assistance with the measurements. Dr Tony F Embleton of the National Research Council provided much appreciated advice and the Canadian Diamond Drilling Association, through its subcommittee under the chairmanship of Henry Skrowronski, gave guidance to the program.

ABSTRACT

This report covers the second phase of a multi part program aimed at reducing the noise level on diamond drills. The work covered includes a definition of the noise level components for surface equipment, a review of some conventional techniques and the design of an engine enclosure.

In general, the noise emanates equally from four sources; namely, the engine, the water pump, the transmission and the drill head.

An engine enclosure has been designed to reduce the engine noise to an acceptable level. Work remains to find solutions for noise issuing from the other three sources. Once this has been done, the complete program must then be repeated for underground drills.

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FORWARD

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SECTION 1 INTRODUCTION

SECTION 2 OBJECTIVES

SECTION 3 OBSERVATIONS

SECTION 4 CONCLUSIONS

SECTION 5 RECOMMENDATIONS & FUTURE WORK

SECTION 6 MEASUREMENTS

SECTION 7 ENGINE ENCLOSURE

SECTION 8 DRIVE NOISE

SECTION 9 NOTES ON REGULATIONS

APPENDIX I

APPENDIX II

DIAMOND DRILL NOISE STUDY

PHASE II

1.0 INTRODUCTION

Recent regulations under the Occupational Health and Safety Act have placed greater emphasis on noise control on all equipment. It is evident that these restrictions will be made even more stringent. Table 1.1, taken from the Ontario Gazette, gives a good indication of the levels that will be expected throughout Canada in the near future.

When these restrictions are applied to new equipment where new models and designs are generated frequently, there is ample opportunity to meet these standards. However, in an industry such as the Diamond Drilling Industry, where new equipment does not reflect new designs and where much of the equipment in use is generally rebuilt and has been used for a number of years, it is far more difficult to meet the noise suppression requirements. Nevertheless, noise levels on diamond drills are known to be exceedingly high with a number of people in the industry suffering from loss of hearing.

To assist the drilling industry in reducing the noise on their equipment, a project, funded by CANMET, was initiated in 1979. Because of the complexity of the overall problem and the need to gear solutions to the drilling industry, the project was phased, with the first phase designed to present an over-view of the problem at hand.

TABLE 1.1

NEW NOISE LEVEL REGULATIONS *

COLUMN 1 SOUND LEVEL dBA	COLUMN 2 MAXIMUM PERIODS IN HRS PER DAY
80	16
85	8
90	4
95	2
100	1
105	1/2
110	1/4
115	1/8
greater than 115	0

COLUMN 1 PEAK SOUND PRESSURE LEVEL dBA	COLUMN 2 MAXIMUM NUMBER OF IMPULSES PER DAY
120	10,000
130	1,000
140	100
greater than 140	0

* Proposed for the Province of Ontario

The first report (Phase I) was presented to the industry in the Spring of 1980 and consisted of a general survey of the types of equipment currently in use in the industry. From this survey, it is evident that approximately 70% of all the equipment is used on the surface and is diesel powered. The remaining 30% is used underground and is pneumatically powered. There is a small number of other drills either electrically powered or gas powered but that number is very insignificant. The noise level for surface mounted, diesel equipment is about 106 dBA. The noise level for pneumatic underground equipment is about 120 dBA. When these figures are compared with the figures in Table 1.1, it can be seen that there is a big difference. At the end of Phase I, the overall extent of the problem was fairly well defined although the exact origin of the noise had not yet been determined. As well, solutions had only been discussed in a general way. A number of specialized products such as mufflers and sound isolation materials had turned up but had not been evaluated.

In the Summer of 1980 the second phase of the project was initiated and is the subject of this report. Its objectives are detailed in the next section but briefly involve a more detailed evaluation of sound sources, the design of an engine enclosure and an examination of some of the available accessories which could be used to reduce noise levels.

The work of both projects was contracted to Heathwood Engineering Associates Limited of Kirkland Lake. Heathwood was assisted coequally by Noranda Research Centre in Pointe Claire, Quebec. Through the Canadian Diamond Drilling Association, a technical committee consisting of diamond drill manufacturers and drilling contractors was established to act as a steering committee for the project. Assistance for the project was also obtained through the National Research Council of Ottawa.

2.0 PHASE II OBJECTIVES

The statement of work (Appendix I) as outlined in the contract provided for a number of objectives.

The Phase I work had established that the overall noise levels were high. It had also established that there was likely more than one source of noise so that no simple solution existed to the overall noise abatement on the diamond drill. The first objective of Phase II was therefore to determine the numbers and levels of noise sources. Two sets of measurements were taken. One set was completed by the Noranda Research Group and was done by classical methods. The second set was done by the National Research Council using a newer, two microphone method. This latter method will be reported elsewhere.

The second part of the work was to examine the best steps in reducing the general noise level as determined in the first step. The main thrust of this work was in the preparation of plans for an engine enclosure capable of sufficiently reducing the engine noise.

As a parallel function, a number of devices in current development were also examined. These devices were a silent power system developed by Hatz, a special muffler developed by Inco and currently produced by State Industries in Winnipeg, Manitoba, a new drill muffler design undertaken by Canadian Longyear and other similar devices.

Actual measurements of the Hatz diesel system and of the State muffler were undertaken.

Finally, recommendations for future work have been included in the final sections of this report for the further consideration of CANMET and the Canadian Diamond Drilling Industry.

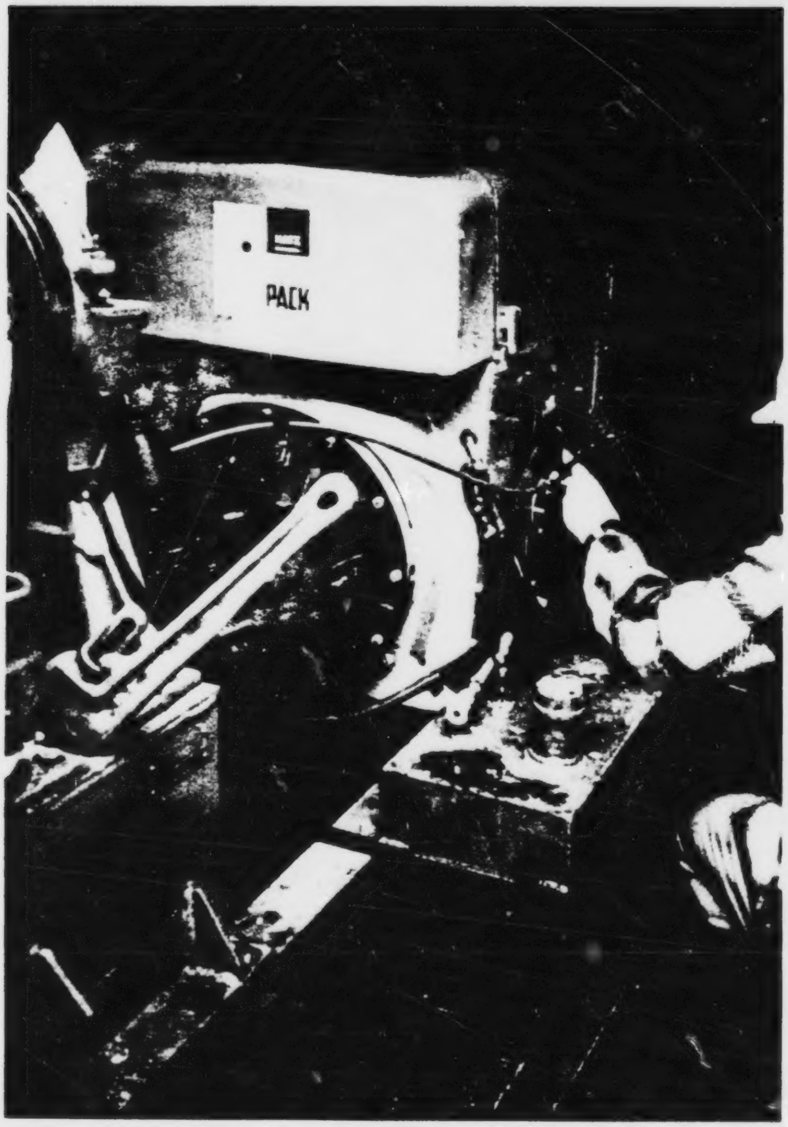

Figure 2.1 The Hatz silent pack mounted on the Boyles Brothers drill.

3.0 OBSERVATIONS

As outlined in the section on Measurements, four separate noise sources were delineated, more from the standpoint of logical grouping of components rather than actual noise source evaluation. The basis for grouping was in terms of treatable elements. The four noise sources were the engine, the transmission, including all transmission components up to the bevel gear driving the head, the bevel gear and head assembly and the water pump assembly. As can be seen from Table 6.1, the levels of each of these components vary by only 3 dBA. The total sound level is 103 dBA.

Work on noise reduction was started with the complete design of an engine enclosure and some preliminary investigations into drive design. The engine enclosure is presently ready for fabrication. It is currently felt that the best solution to reducing the transmission and head noise is by means of more effective drive design. This has been discussed with gear manufacturers and experts in the gear industry. The concensus at the moment is, that while it is possible to reduce drive noise by better drive design, no one is sure of the trade-off levels. It may be possible that the existing transmissions can be used with a simple replacement of more precise gearing and shafting. On the other hand, it may also be possible that the entire transmission would have to be scrapped in order to achieve sufficient noise reduction.

Exploratory work was done on the use of the Hatz quiet diesel engine and the State and Cowl mufflers (see Appendix II) as a means of silencing pneumatically powered underground drills. On the test drill, the Hatz produced a sound level of 90 dBA, down 8 dBA from the more conventional Deutz engine. As indicated in Section 6, both the State and Cowl mufflers reduced exhaust noise emanating from the water pump which was a vane type motor. However, they brought about no apparent benefit when used with the piston motor driving the drill. It would appear that the noise from the bevel gear and other drive components in the drill is the over-riding factor.

4.0 CONCLUSIONS

4.1 In order to meet the 85 dBA level*, all four noise sources must be reduced to 80 dBA each.

4.2 The engine enclosure should be constructed and tested as soon as possible. While the enclosure is not difficult to construct, there are a number of areas where close attention to detail will be required. For this reason, it is suggested that the enclosure be constructed by an expert in the field, or by a competent contractor and that it be done under the close supervision of an engineer.

4.3 The Hatz engine does not reduce the sound level to the 80 dBA limit required. The noise level is in fact 90 dBA. It would not appear to be practical to place the engine within a second enclosure.

4.4 While tests to date on the underground pneumatic drill were not conclusive, it would appear that special attention should be given to the bevel gear and drive components and possibly to the gears operating the screw feed.

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* This is dependent on the regulations. If the regulations were changed to 90 dBA then the design level would be 85 dBA.

5.0 RECOMMENDATIONS AND FUTURE WORK

Future work will depend on the funding available. The following recommendations are given, therefore, in order of highest priority.

5.1 Throughout the program continue to provide assistance in connection with all communications between the Canadian Diamond Drilling Association and authorities having jurisdiction over noise control and continue to examine new methods as they become available.

5.2 Construct an engine enclosure as outlined in the engineering drawings supplied separately as part of this work. When the enclosure has been constructed, mount the enclosure on a drill and have sound level measurements taken to assess its suitability.

5.3 Re-examine the previous priority stating that a screw feed head should be the first to undergo noise reducing modifications. This head will be the most expensive head to work with because of the extra components.

5.4 In conjunction with specialists and drive component manufacturers, evaluate methods of reducing the noise level of all power transmission components in terms of cost and effectiveness. Be prepared to undertake some experimental work in connection with this evaluation.

5.5 Assist any member of the Canadian Diamond Drilling Association willing to make noise reducing modifications to their drilling equipment with technical backup, measurement and evaluation.

5.6 Make detailed measurements on the underground drills to identify major noise sources and levels.

5.7 In conjunction with a specialist, examine the pneumatic motor freezing problem to determine possible solutions.

5.8 Transfer all similar solutions used to reduce surface drive component noise to underground drive components.

5.9 Develop a standard method of noise level measurement to be formally adopted by the Canadian Diamond Drilling Association.

6.0 MEASUREMENTS

The main thrust of measurement activities focused on a "typical" diesel-powered surface drilling rig as planned at the outset of the program. The objective was to identify and quantify all major noise components on the rig. While preparing to carry out these measurements, an opportunity arose to conduct some noise measurements on a drill equipped with a Hatz "silent power" diesel. This opportunity was seized even though the measurements carried out were not as extensive as would have been preferred.

It was also possible to subsequently carry out some preliminary measurements on a pneumatically-powered drill being operated underground. Both this drill and the diesel-powered unit were owned and operated by the Diamond Drilling School at the Northern College of Applied Arts and Technology in Haileybury, ontario, without whose cooperation the measurement portion of the program would not have been possible. Except for the Hatz diesel, all measurements were carried out under normal drilling conditions.

The surface rig studied was a Boyles Model BBS-15 with mechanical screw feed, normally powered by a two-cylinder (26 KW) air cooled Deutz diesel. A three-cylinder (29.8 KW) Hatz Model 3L30C "silent power" diesel was temporarily adapted to the drill by Morissette Diamond Drilling Limited for trial purposes. The drill was housed in a typical plywood shack (12' x 16' x 8') as shown in Figure 6.1.

6.1 Deutz Diesel Measurements

In order to be able to measure the effect of suspected noise components alone, each was operated separately whenever possible, and under the most severe operating conditions (e g engine operating at wide open throttle with the transmission in

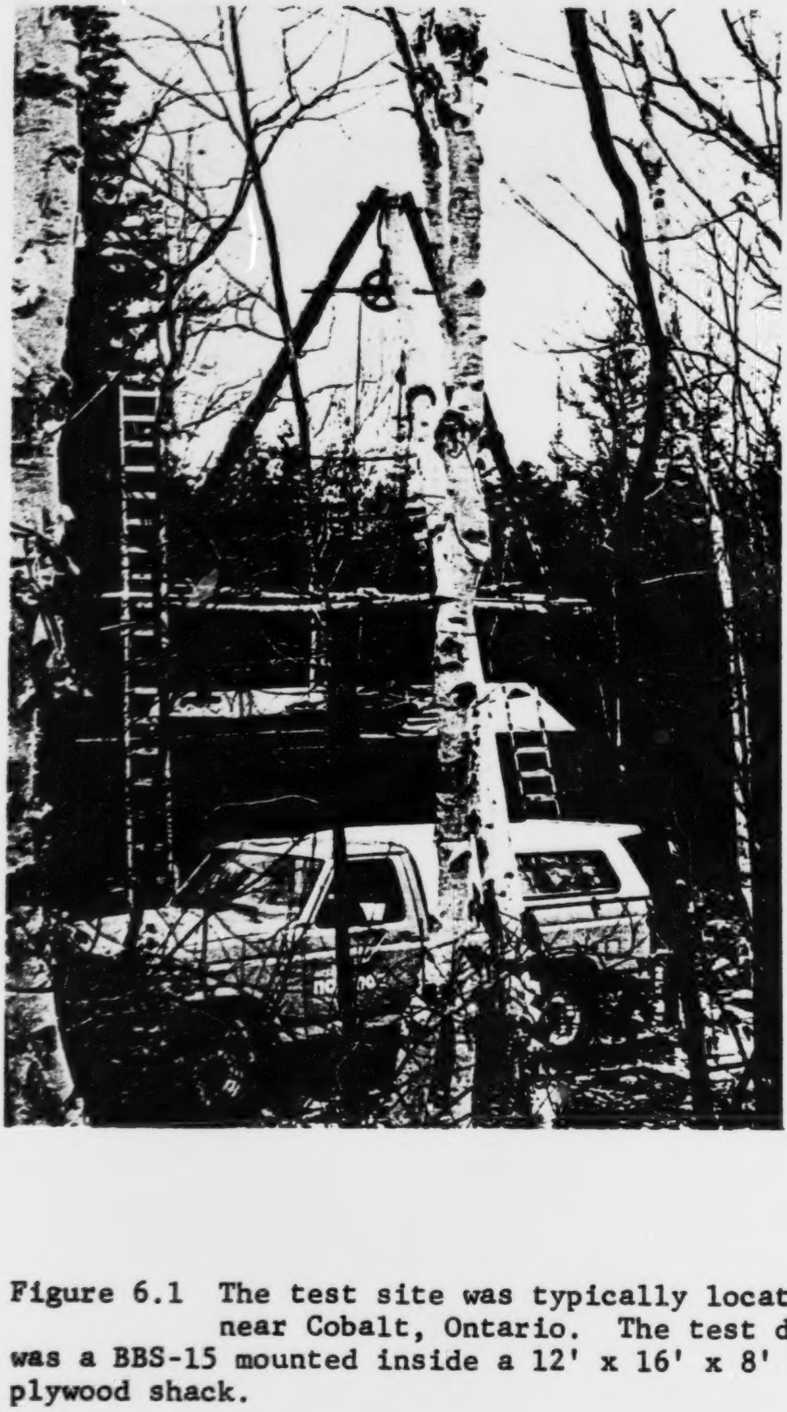

Figure 6.1 The test site was typically located near Cobalt, Ontario. The test drill was a BBS-15 mounted inside a 12' x 16' x 8' high plywood shack.

neutral to measure engine noise emissions). For components like the bevel gears which could not be operated alone, an acoustical barrier was erected between the component of interest and other noise sources to reduce the noise level of the disturbing components to at least 10 dB below that of the component of interest. In this way, mixing effects were minimized.

Noise measurements were repeated in several predetermined locations around the drill and outside the drill shack under each set of conditions (e g engine alone, engine plus transmission, etc), but unless otherwise indicated, only those values from the operator's normal working position near the head are reported, since this is the data most pertinent to a drill operator's typical noise exposure.

Measurements were carried out using a GenRad Model 1933 precision sound level meter equipped with a 1/2 inch electric condenser microphone mounted on a 60 foot extension cable. Select signals were output to a Nicolet Model 446A real-time spectrum analyzer (equipped with a digital plotter) when a narrow band frequency analysis was desired (i e 400 line resolution). The instrumentation setup is shown in Figure 6.2.

The results of several narrow band analyses were superimposed on one graph and are shown in Figure 6.3. The vertical scale is A-weighted sound pressure level (i e approximately the same as would be heard by the human ear), and the horizontal scale is frequency. The 0 to 10 kHz frequency range shown is approximately the same range normally attributed to the hearing capability of adults. Inspection of Figure 6.3 indicates that most of the noise components observed have the bulk of their sound energy in the 500 to 3000 Hz range. This corresponds to the speech frequency range (the most prevalent frequencies of speech) and

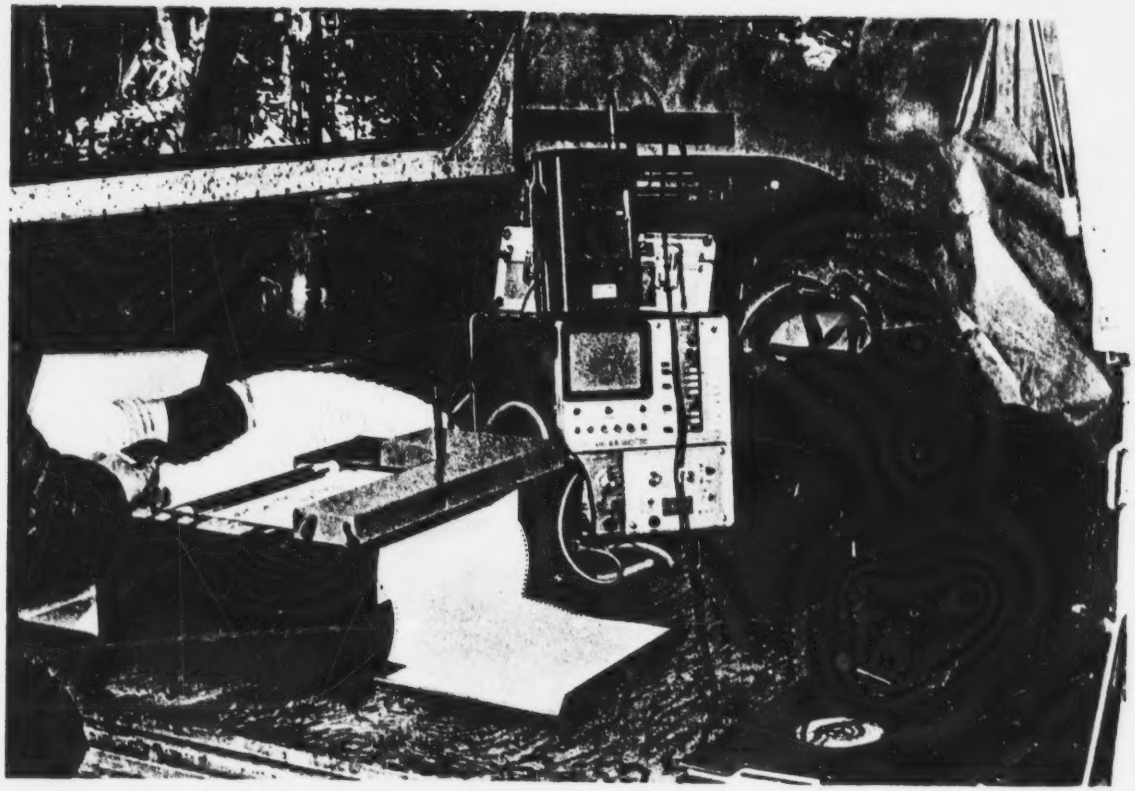

Figure 6.2 The measurement instrumentation setup for the Deutz diesel engine

(GenRad type 1933 precision sound level meter with a
Nicolet type 446A real time spectrum analyzer and digital plotter)

NOISE SPECTRA OF DIAMOND DRILL EQUIPPED WITH DEUTZ DIESEL

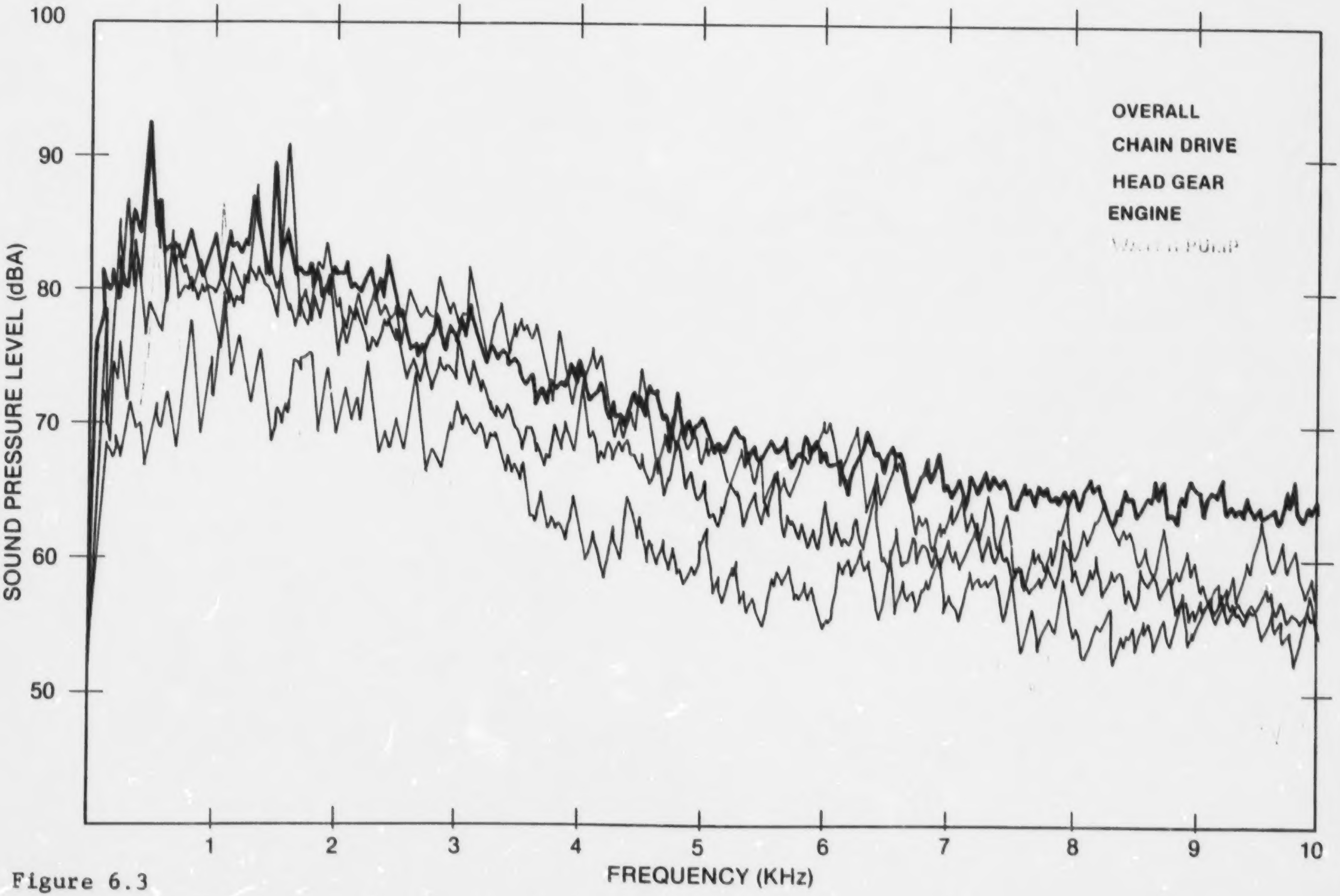

Figure 6.3

represents a significant risk in terms of hearing damage potential.

The relative importance of each noise component is illustrated by the overall height of each curve in Figure 6.3, but is more readily discerned by examining the corresponding overall dBA levels* for each, as summarized in Table 6.1. It should be noted that the test engine was equipped with an exhaust muffler, so exhaust noise was not a major component in this study. The dBA values shown in Table 6.1 are the same as those used in provincial noise regulations. It is obvious, therefore, that the eight hour exposure levels of 85 or 90 dBA currently allowed by provincial noise regulations are exceeded by each noise component.

TABLE 6.1

DEUTZ DIESEL DRILL NOISE SOURCES IN ORDER OF PRIORITY

(Ref Operator Position)

SOURCE	dBA	% SOUND ENERGY
(I) ENGINE	98	33.3
(II) HEAD GEAR (+ DRILL IMPACT)	97	26.4
(III) WATER PUMP	96.5	23.6
(IV) CHAIN DRIVE	95	16.7
TOTAL	103	100.0

---

* i e the sum of energy under each curve

Perhaps less obvious is the logarithmic characteristic of noise. That is to say, if one were to completely eliminate one of the major noise components, it may not be clear what net effect this would have on reducing the overall noise level. To illustrate this, the values in Table 6.2 were calculated. It is seen that elimination of engine noise only would reduce levels from 103 to 101 dBA, etc. This underscores the fact that all major noise components have to be treated before compliance with noise regulations can be achieved.

TABLE 6.2

EFFECT OF ELIMINATING NOISE COMPONENTS

COMPONENTS ELIMINATED	RESIDUAL dBA
NONE	103
ENGINE	101
ENGINE & HEAD GEAR	99
ENGINE & HEAD GEAR & WATER PUMP	95
ENGINE & HEAD GEAR & WATER PUMP & CHAIN DRIVE	90

A more sophisticated analysis technique was tested by the National Research Council on the same drill one week prior to the measurements described above as a check on the technique in the event that it might prove useful in the future. Virtually identical results were obtained, so they will not be discussed in this report.

6.3 Hatz Diesel Measurements

Measurements on the Hatz diesel were carried out at the same location as the Deutz, but the drill was not in operation at the time. Furthermore, the measurement team was visiting the site in preparation for the Deutz study, so was not equipped to conduct a set of measurements like those previously described. It was possible, however, to operate the Hatz diesel by itself and with the head gear turning but no drilling taking place. Overall noise levels (dBA) were measured using a Bruel & Kjaer type 2205 sound level meter equipped with a 1/2 inch condenser microphone. Tape recordings of major noise components were made on a Nagra SN tape recorder and subsequently analyzed on the Nicolet spectrum analyzer previously described.

Key results are shown in Figure 6.4. As with Figure 6.3, the vertical scale represents A-weighted sound pressure level and the horizontal scale is frequency, but in this instance over the range 0 - to 2000 Hz. Since there was no means of isolating each noise source individually, measurements for the narrow band analyses were made within 2 inches of each source. For this reason, absolute noise levels observed are higher than what would normally be heard approximately three feet away. However, amplitude and frequency information are meaningful relative to each other, because the microphone position from each source was held constant. It is seen that with the Hatz diesel in place, the head gear (plus chain drive and gear tower assembly) becomes the dominant noise source. The dBA values noted in parentheses are overall noise levels measured three feet away from each source, except for the transmission value. The latter number (80 dBA) is an approximation based on an estimate of the decrease in sound pressure level which would result by moving the microphone three feet away from the source.

NOISE SPECTRA OF DIAMOND DRILL EQUIPPED WITH HATZ DIESEL

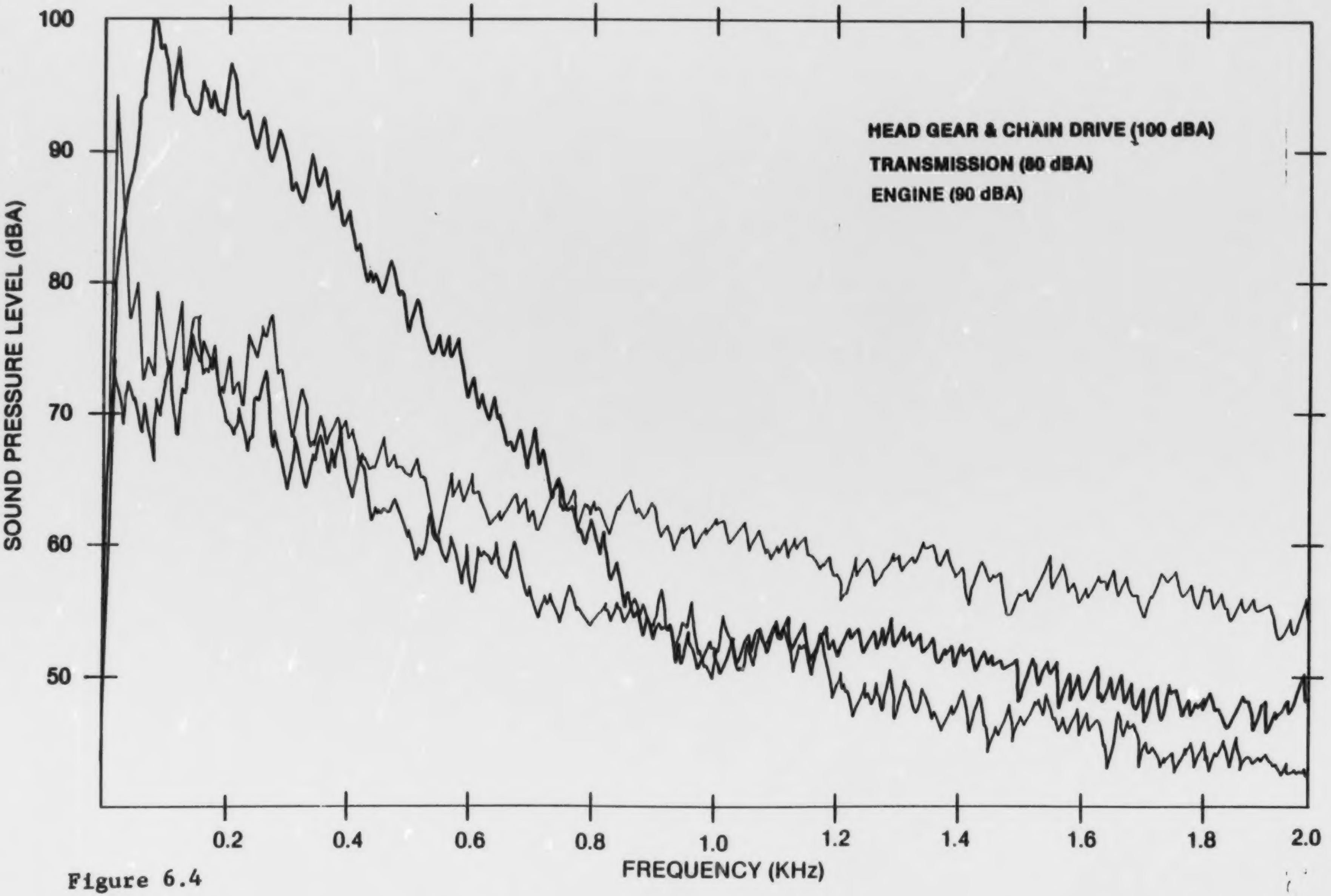

Figure 6.4

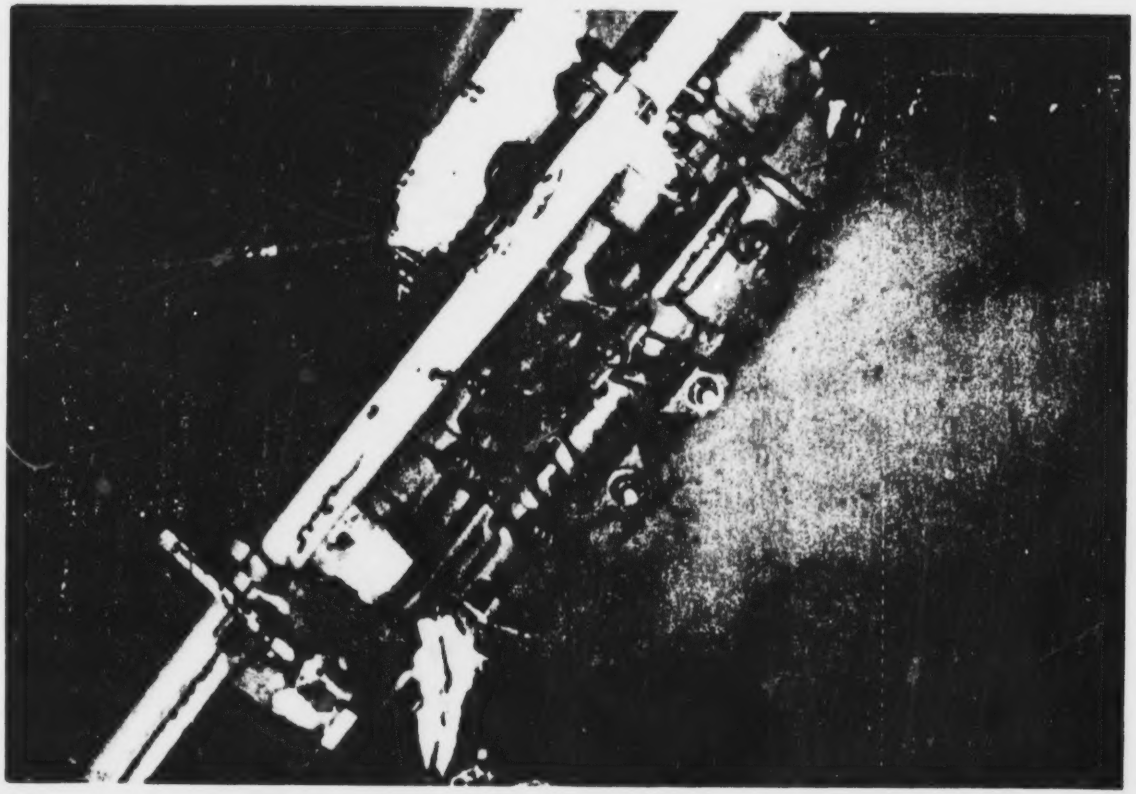

Figure 6.5 The temporary bulkhead positioned behind the drill head to isolate the sounds of the engine and transmission.

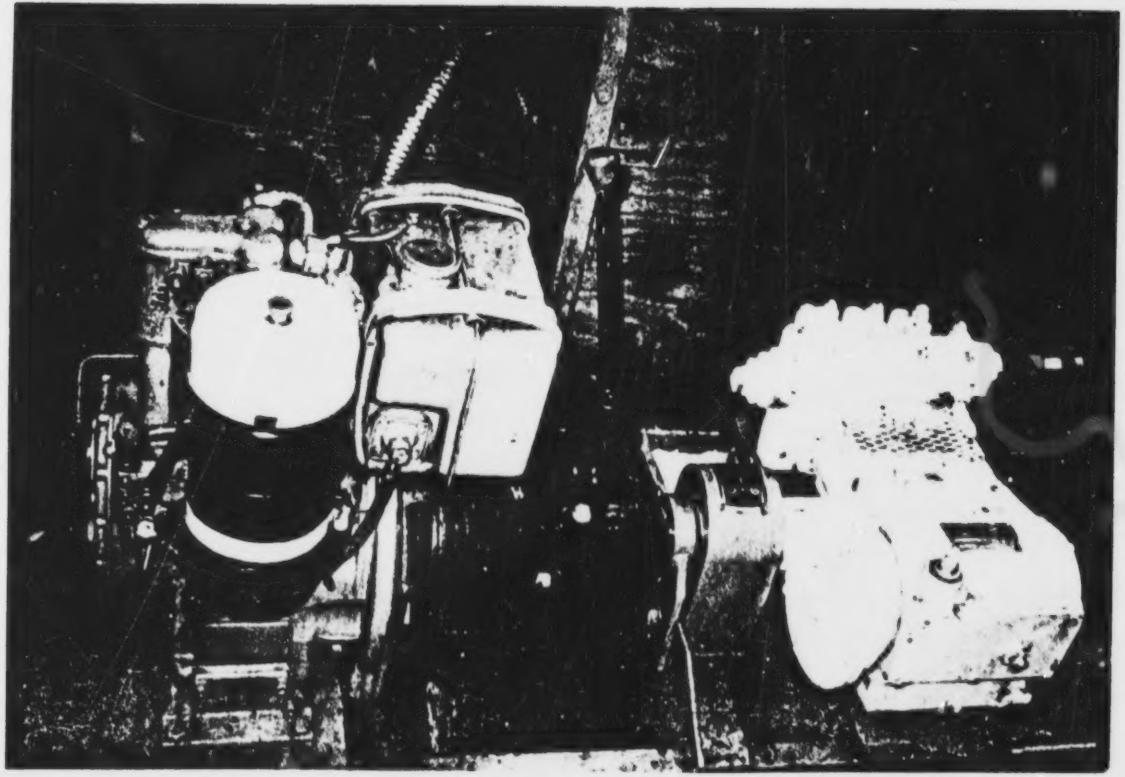

Figure 6.6 The water pump used for the test was powered by a Hatz diesel engine.

Comparing the Hatz and Deutz data, it is evident that the Hatz engine operates at a noise level 8 dBA lower than the Deutz (90 and 98 dBA respectively) in the test environment. The 100 dBA level measured near the head gear with the Hatz engine agrees very closely with the sum of the head gear and chain drive components (99 dBA) measured separately during the Deutz engine study. The water pump noise level would remain the same in either case.

6.3 Pneumatic Drill Measurements

Pneumatic drill tests were conducted in an underground drift having a "Y" configuration when viewed in plan, with approximate cross-section dimensions of 10' x 10' x 7'. The drill was located at the junction of the "Y", with the water pump located approximately 8 to 9 feet away along one branch of the "Y", and the drill exhaust hose strung out approximately 25 feet along the other branch, in the direction away from the drill.

Prior to the conducting of these measurements, State Industries Limited of Winnipeg expressed interest in having evaluated a muffler which apparently was being tested on pneumatic diamond drills by the Manitoba Division of Inco Metals Company. Arrangements were made to test their Model 5A and 2-3 mufflers and it was decided to include tests on a Cowl Model TS25SR spiral muffler for comparison purposes. The latter unit had been previously used on the Deutz diesel and was used in this study because it was available.

Measurements were conducted with the GenRad precision sound level meter described previously. Tape recordings for subsequent spectrum analysis were planned, but instrumentation problems experienced on-site prevented recordings from being made.

Results of this study are summarized in Table 6.3. It should be noted that numerous inconsistancies were noted upon examination of the original data. These are believed due to fluctuations in drill air-supply pressure during testing and undersizing of the mufflers used in the tests. The data for the drill in Table 6.3 is for levels measured in the operator's position unless otherwise indicated, and was selected as the best indicator of the patterns which appeared to be emerging. Water pump data was measured three feet from the pump with the pump operating by itself. All data should be regarded as preliminary results rather than data on which firm conclusions can be drawn.

Both the State and Cowl mufflers reduced exhaust noise from the water pump, with the Cowl muffler achieving the greatest reduction. The State muffler was left on the water pump to avoid interference effects with subsequent measurements to be conducted on the drill.

Two sets of measurements were then conducted with the Cowl and State mufflers consecutively installed directly on the drill's air motor exhaust and two different sets of results were obtained.

Variations may have been the result of line pressure fluctuations, restrictions in air flow due to undersized mufflers, freezing inside the mufflers, etc. However, no major changes in test conditions were apparent. Therefore, it is difficult to conclude whether any real improvement in noise level was observed when using either muffler or the original hose on the motor exhaust.

When measurements were made along the exhaust hose (3' from drill, 6' from drill, etc), it was interesting to note that noise levels dropped off to 94 dBA. This suggests that the noise levels being measured near the drill while the hose or a muffler is in place are the result of something

TABLE 6.3

SUMMARY OF PNEUMATIC DIAMOND DRILL MEASUREMENTS

NOISE SOURCE	TEST CONDITION	NOISE LEVEL (S) IN dBA
WATER PUMP (BB4-7M 4" VANE TYPE 11 HP)	NO MUFFLER	102
	STATE MUFFLER (#2-3)	97
	COWL MUFFLER	91
DRILL (BBS JV 2 CYLINDER "V" TYPE 27 HP)	NO EXHAUST HOSE OR MUFFLER	109.5 111*
	NORMAL EXHAUST HOSE	108.5
	COWL MUFFLER ON DRILL	103 109*
	STATE MUFFLER (#5A) ON DRILL	105 105*
	EXHAUST HOSE ONLY (@3' 6' 12' 25')	108.5 105 99 94
	EXHAUST HOSE + COWL MUFFLER ON END	110 105 98.5 94.5
	EXHAUST HOSE + STATE MUFFLER ON END	105.5 104 102 107
	LAGGED EXHAUST HOSE ± COWL MUFFLER	106.5 101.5 99 93.5
	LAGGED EXHAUST HOSE + STATE MUFFLER	108.5 104.5 103.5 101

* duplicate tests

other than the air motor exhaust. In fact, the subjective feeling of those doing the measurements was that the bevel gears were the dominant noise source under these operating conditions. Installing a Cowl muffler at the end of the exhaust hose and lagging the exhaust hose with fibreglass had virtually no effect on further reducing exhaust noise levels. Similar tests with the State muffler increased noise levels at and near the end of the exhaust hose, suggesting the muffler was restricting air flow and thereby increasing air turbulence and hence noise at that point.

Due to the anomalies which were observed in this data, additional tests will be required before valid conclusions can be drawn. In that event, line pressures should be controlled and mufflers, etc used in tests should be sized carefully to avoid flow or other unsuspected problems. Meanwhile, available data does suggest that initial noise control efforts for pneumatic drills should be directed at the bevel gears rather than at the air motor exhaust.* This is encouraging in that work done to reduce bevel gear noise for surface rigs should be adaptable to underground rigs.

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* assumes exhaust hose is in use on drill. Muffling of water pump air motor exhaust could be beneficial as illustrated by Table 6.3

7.0 DIAMOND DRILL ENGINE ENCLOSURE

7.1 Objective

The objective of this portion of the project was to design an engine enclosure which would reduce the sound level of the engine used on a diamond drilling rig to 80 dBA at the operator's station. The design principles developed can be applied to any engine, but the engine used in the drawings was a General Motors Model 3-53 diesel engine. This engine is a three cylinder, blower aspirated, two stroke cycle, water cooled power unit.

The enclosure for the engine must meet several other conditions in addition to a reduction in sound level. These are:

a) Performance of the engine must not be reduced to any significant degree.
b) The operation of the engine cannot be hampered.
c) The sound enclosure must not create a fire risk.
d) All maintenance points must be easily accessible.
e) The enclosure must disassemble without great difficulty to allow for engine changeout.
f) The enclosure must be durable enough to withstand the abuse received in a drilling camp.

7.2 Noise Attenuation

The overall noise level of the engine is the result of the logarithmic addition of all the individual noise sources. These sources include the combustion process, the fan, intake blower, exhaust, valve train, injectors, pumps, etc. To attempt to individually isolate all the noise sources is impractical and an overall enclosure was designed. Engine manufacturers are in the process of redesigning individual machine components to reduce noise levels at the point of generation. This program will take many years to complete, however, and will do little to quiet the engines which are already in use.

Ideally, an overall engine enclosure would not contain any openings and a simple sound barrier of sufficient density would be adequate. However, reality dictates that several openings must be provided for the following reasons:

a) to introduce fresh cooling air
b) to discharge hot cooling air
c) to discharge engine exhaust gases
d) to pass wiring and control cables, hoses and drive shafts
e) for service access.

7.2.1 Nature of Sound

Sound readings used in the design of this enclosure were taken from a diamond drill equipped with a Deutz diesel. Actual sound readings for a General Motors diesel were not available. However, it was assumed that the Deutz diesel would likely be noisier due to the fact that the engine was cooled with air and not with water.

Sound levels were as shown in Table 7.1.

TABLE 7.1

OCTAVE BAND CENTRE	LEVEL dBA
63	70
125	78
250	87
500	94
1K	83
2K	93
4K	78
8K	70
TOTAL COMBINED SOUND LEVEL =	98 dBA

To reduce the sound levels, the engine enclosure has been designed as follows.

7.3 Enclosure Design

7.3.1 Enclosure Wall Configuration

The walls of the enclosure are constructed from 22 gauge sheet metal lined with a 1 inch thick sheet of fibreglass acoustical insulation. To prevent the fibreglass from becoming saturated with oil or dust, a 1 mil sheet of Dupont kapton plastic film will be used to encase the fibreglass. Kapton film was chosen for this application because of its high temperature resistance and physical strength. The film is suitable for constant service at 220 degrees Centigrade (428 degrees Fahrenheit) and will not burn. The film will be wrapped over the fibreglass and the assembly will be glued to the wall. A protective sheet of perforated metal will be placed over the insulation to prevent accidental puncturing of the film.

The bottom of the engine enclosure is fabricated from 11 gauge mild steel and is not lined with fibreglass insulation. The bottom of the enclosure will be continually wetted with oil, diesel fuel and water. Lining this area would create a fire hazard and impede the flow of liquids to the drain. Heating devices such as gas torches are often used to warm engine oil pans for starting in severe weather. Direct contact of the flame from the torch on any film covered insulation in the bottom of the enclosure would destroy the film. The absence of insulation on the bottom and the heavy gauge thickness of the plate will prevent this area from being damaged in the field.

7.3.2 Cooling Air Inlet

To provide cold air for the radiator, provision must be made for drawing air into the enclosure without letting the noise out. Noise at the inlet consists of the logarithmic addition of the engine noise to the fan noise. The present inlet design has a minimal resistance to air flow with effective sound attenuation. The sound leaving the enclosure inlet has direct and reflective transmission properties. The direct transmission properties are eliminated by the physical configuration of the inlet; that is, the sound source does not have a direct line of sight to the inlet opening and the reflective properties are absorbed by the 1-1/2 inch thick fibreglass lining. The fibreglass lining is plastic covered and protected with perforated metal as described in Section 7.3.1. A thicker lining is required in the inlet area to increase the absorption of the lower frequency sound waves.

Noise level from the inlet will be 80 dBA.

7.3.3 Cooling Air Outlet

To provide cooling air for the engine, provision must be made for discharging the air from the engine enclosure without letting too much sound out. The design parameters for the outlet are similar to the parameters mentioned in the cooling air inlet. The outlet is arranged so that direct transmission of the sound is not possible and reflective transmission is impeded. The only difference between the two conditions is that fan noise is not a consideration in the outlet design. Noise levels from this source will also be approximately 80 dBA.

7.3.4 Exhaust Noise

To suppress the noise from the engine exhaust system, a Cowl muffler is mounted in the exhaust system. The Cowl muffler has high sound attenuation properties with minimal exhaust restriction and should bring the noise levels from this source to well below 80 dBA. The muffler is located within the enclosure and isolated from the walls of the enclosure with a short piece of flexible exhaust piping. A pipe thread is provided where the flexible pipe is connected to the enclosure so additional piping can be added to discharge the exhaust outside the drill shack.

7.3.5 Air Breather Noise

An air inlet silencer must be installed on all two stroke diesel engines with inlet blowers. The General Motors engine used as a model for this design was so equipped. To ensure that the engine always receives cool air from outside the enclosure, it is necessary to seal the air inlet filter from the remainder of the engine. The sound level produced with the filtered inlet can be further reduced by locating the inlet box in a recessed enclosure as shown on the drawings. The position of the air inlet port with respect to the face of the air inlet filter ensures that very little of the directly radiated sound will escape the enclosure. Reflected sound levels will also be reduced by the 1-1/2 inch thick insulation used on the air filter enclosure walls. A sound reduction of approximately 10 dBA can be expected from the inlet configuration.

7.3.6 Transmission Noise

A considerable amount of noise is released from the engine transmission. To reduce noise levels from this source, the transmission has been totally enclosed in a manner similar to the rest of the engine. To allow protrusion of the gear shift lever and the drive shaft, flexible bellows made of high density sound attenuating rubber have been installed. The rubber bellows will allow free movement of the components without a significant increase in sound levels.

The clutch shaft from the transmission has been fitted with a flexible coupling and the shaft has been extended through the enclosure wall. A ball joint is mounted where the shaft passes through the enclosure to permit free movement of the engine on its rubber mounts.

Ample space has been provided around the transmission to allow the engine cooling air to also cool the transmission.

7.4 Engine Cooling System

The addition of the engine enclosure severely impedes the flow of air around the engine and through the radiator. To meet the original design criteria it is necessary to maintain a sufficient flow of air to the engine without a loss in horsepower output. The original propeller fan supplied with the motor is cheap, compact and light, but it is not very efficient and will not move large volumes of air if there is too much resistance to air flow.

7.4.1 Impeller Design

The fan configuration required for this application must move slightly more air at greater resistance than the original fan but cannot require a greater amount of horsepower from the engine. To meet this criteria, a more efficient, backward inclined fan with an airfoil blade was selected. This fan meets the above requirements and has the added advantages of turning at about the same speed as the original unit but with a lower noise level. The fan requires approximately the same amount of room as the propeller unit and must be installed with an air inlet cone to obtain the necessary performance criteria.

7.4.2 Radiator Design

The present radiator used on the engine will supply adequate cooling in the new enclosure with the new radial fan. Additional gains in sound control, cooling efficiency and space utilization could be achieved if a donut shaped radial radiator was installed. Inquiries for a radial radiator were made, but with little success. The tooling required for a radiator of this configuration does not appear to exist on this continent. A proposal was made by one supplier to fabricate a square radiator with radial air flow characteristics, but the price of $2000 a unit was not feasible. Engine vibrations often break the existing radiators and it was felt that the design should utilize a unit which was readily available.

7.5 Engine Maintenance Accessibility

For a successful enclosure design, it is essential that all the engine maintenance functions be performed without interference from the engine enclosure. Doors and removable covers have been located on the enclosure so that this criteria is met. All doors are sturdily constructed and must seal effectively when closed. Neoprene foam is used for gasketing on all openings.

7.5.1 Hinged Side Doors

Large hinged doors are installed on both sides of the enclosure to provide access to the most commonly serviced engine components. Through these doors, access can be made to the oil and fuel filters, the oil drain plug, the fan belt, the inlet and exhaust manifold, the water pump, the oil cooler, the alternator and the oil breather tube. These doors are equipped with slip-joint hinges and can be easily removed if necessary.

7.5.2 Top Access Hatch

The top of the engine enclosure unlatches and flips back to provide access to the engine valve covers, fuel injectors, radiator, muffler and air breather. The top access consists of two hatches; one directly over the engine and another over the radiator. Both doors can be opened independently. The cooling air exhaust plenum is an integral part of the engine cover hatch and is therefore moved out of the way when the hatch is opened.

The overhanging front of the hatches is also hinged to provide easy access to the air breather without raising the entire top of the enclosure.

7.5.3 Back Covers

Covers at the back of the engine enclosure, directly above the transmission, provide access to the hydraulic pumps and the oil dip stick. These covers are equipped with slip-joint hinges and are of the same construction as the other doors.

Hoses from the hydraulic pumps are piped to a common bulkhead on the engine enclosure. When operators are setting the drill up in the field, it will not be necessary to enter the enclosure to hook up the hydraulic lines. All connections will be made outside the enclosure.

7.5.4 Transmission Cover

A small hinged door is provided on the top of the transmission cover to inspect the transmission oil level and to add fluid. The fill and drain ports on the transmission will be piped to facilitate use of a dip stick.

7.5.5 Fluid Drains

To safely drain fluids from the engine, it is necessary to pipe all major drainage points out of the enclosure. The bottom of the enclosure acts as a large drainage pan to collect miscellaneous oil leaks and direct them to a central enclosure drain.

Fuel oil is drained from the fuel oil filters before engine start-up. The discharge valves on the bottom of the filters are to be piped to a location directly above the enclosure drain hole.

Crankcase oil is normally drained directly from the oil pan. To prevent this oil from splashing over the bottom of the enclosure, a second pan will be installed directly under the crankcase drain. This pan will collect the oil and direct it to the main enclosure drain.

The radiator drain will be piped to a point below the engine and not to the main enclosure drain. This arrangement will allow draining of the radiator coolant without fear of contamination from the engine oil and fuel oil residue in the main enclosure drain.

7.6 Enclosure Disassembly

The enclosure is constructed of separate panels consisting of left and right side panels, top panel, forward frame, rear frame, cooling air inlet enclosure, top and side transmission cover and the enclosure bottom panel. The bottom panel forms the main frame of the enclosure and the majority of panels are fastened to it. All panels are bolted together and sealed with gasketed seams. All hoses, electrical wires and control cables are routed through the rear frame. Where possible, the wires and cables are equipped with fittings for ease of engine removal. With a tripod or pitman, the engine can be withdrawn and replaced by removing only the side panels, transmission cover and top cover. The radiator and fan would stay within the enclosure.

The enclosure assembly is mounted on skids to permit winching of the unit in and out of the drill shack.

7.7 Drill Shack Modifications

The radial fan and cooling ducts make the sound reduced engine longer than a standard engine. The enclosure is 2 feet 6 inches longer and 1 foot 6 inches higher. The end of the drill shack must be extended and the roof will have to be raised to a minimum height of 9 feet 0 inches. The increased height is needed to open the access doors.

Additional modifications will also be required on the main drilling frame. The enclosure is taller and wider than the conventional engine and a special frame will have to be designed to support the unit.

8.0 DRIVE NOISE

While an evaluation of gear components was not a specific requirement of Phase II some exploratory work was undertaken in order to be able to make recommendations for future work.

In general, the gears and other drive components in use on diamond drills were designed a number of years ago and replacements are based on the old design. There are a number of instances of gear failure on the drills indicating either weakness in design or misalignment. Both of these are not conducive to quiet operation.

The gear train in use consists of spur gears and a bevel gear. A change box is often incorporated into the spur gear design. The bevel gear is used as the means of disconnecting the drive when the head is swung away to permit rod pulling. The hinge and catch system does not permit precise alignment over the life of the machine.

There are a number of instances of quiet gears on the market such as the use of helical rather than spur gears and spiral bevel or hypoid instead of bevel gears.

Drive noise levels increase with power and with pitch line velocity. The noise is very complex due to the fact that it is the result of an interaction between tooth meshing errors, which cause oscillations which in turn create shaft deflections, bearing loads and housing oscillations. If the housing oscillations result in a resonant condition, the noise may actually be magnified.

Table 8.1 provides a list of design methods that can be used to reduce drive line noise. Some of these, such as the use of helical gears are reliable and have been used for years. Others, such as the use of phasing, are not as reliable and must be attempted cautiously.

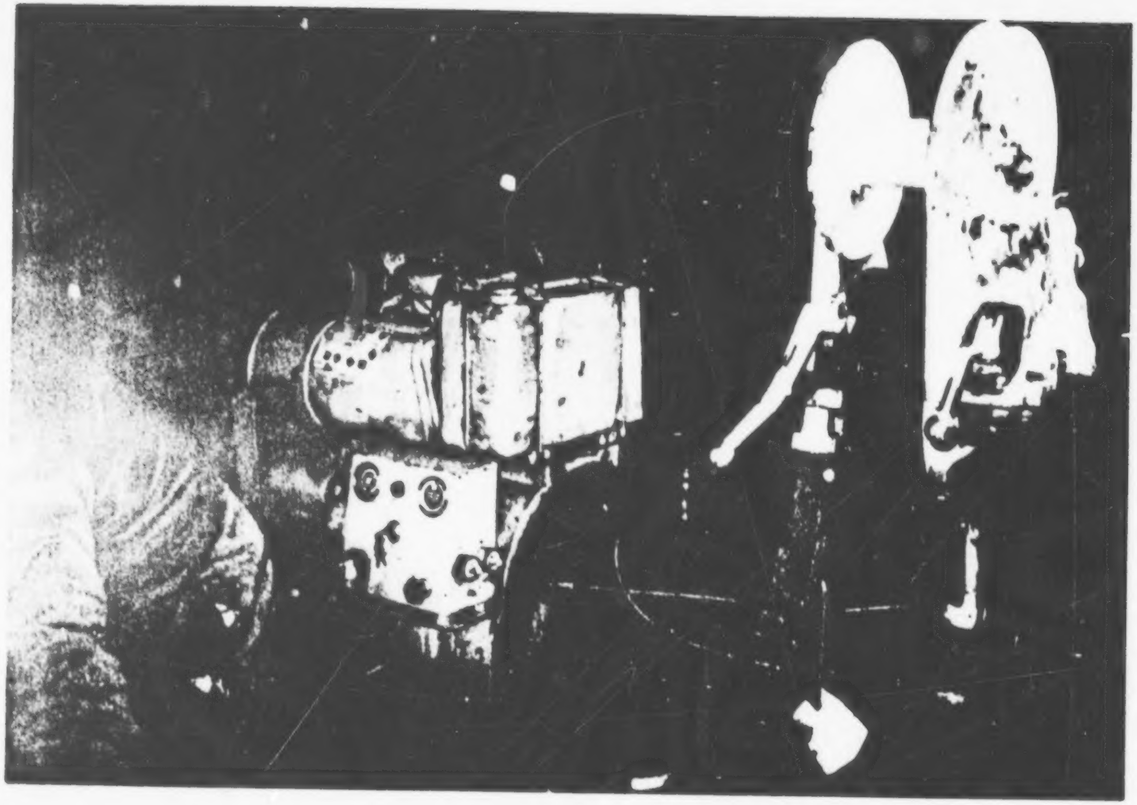

Figure 8.1 A view of the hoist drill transmission and automotive transmission. It would be difficult to provide an enclosure for the drill transmission.

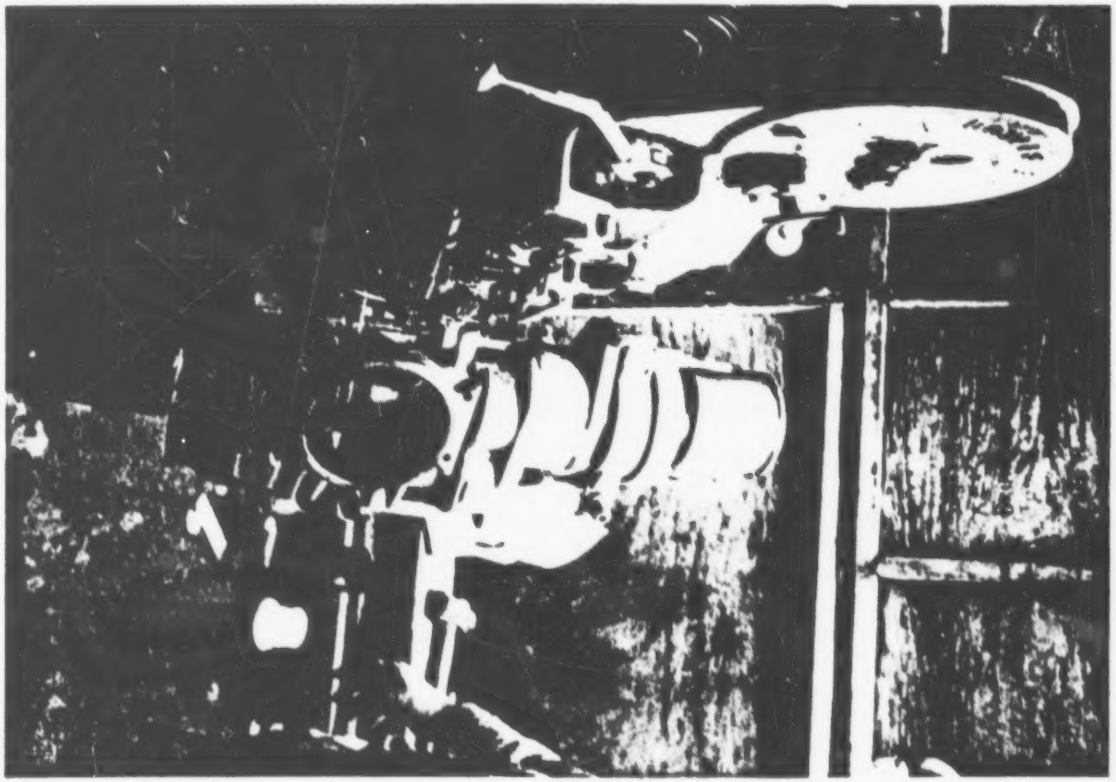

Figure 8.2 The head swings away from the drill to allow room to pull the rods. The bevel gear produces a great deal of the noise.

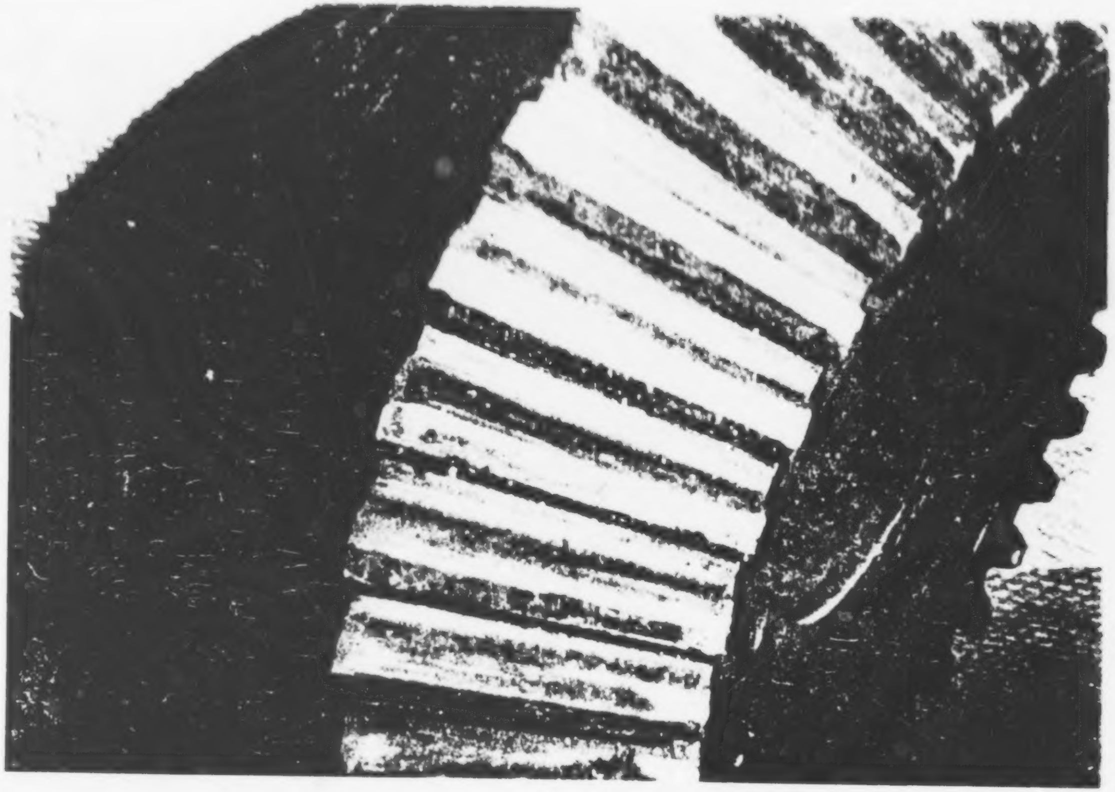

Figure 8.3 A close-up of a bevel gear showing tooth damage.

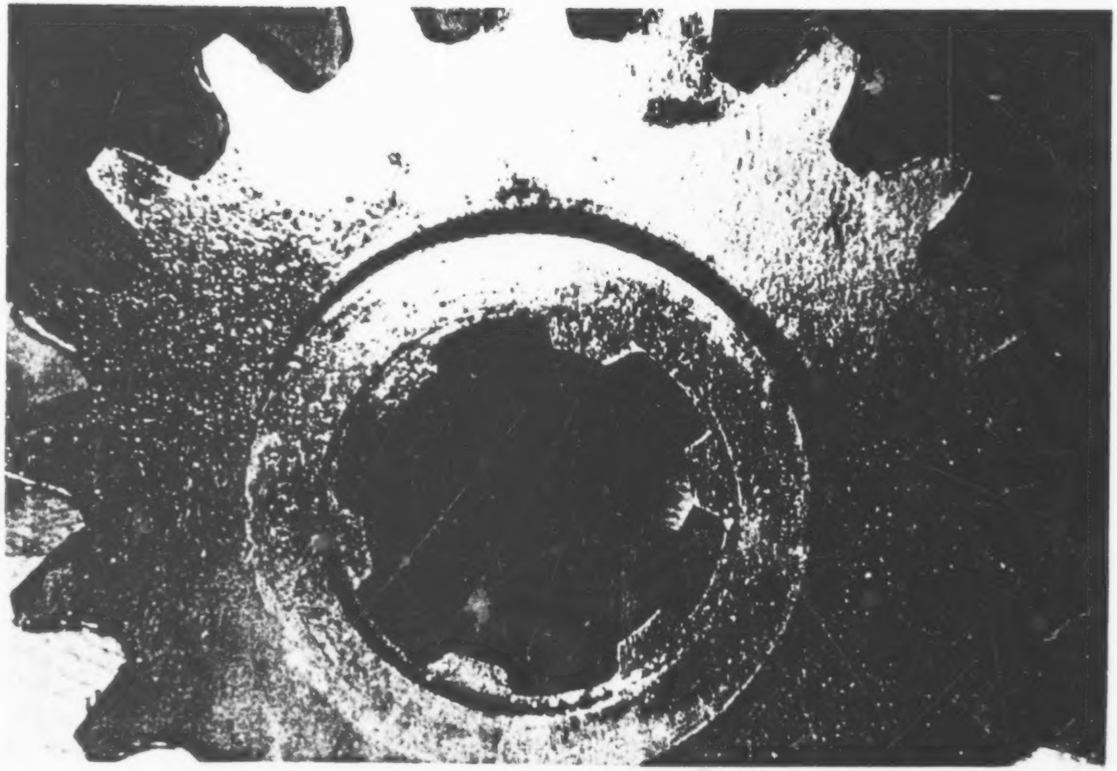

Figure 8.4 A close-up of a spur gear showing spline and tooth detail. Note the tooth damage.

It should also be noted that housing resonance, if it occurs, will completely negate any gains made by other means. This over-riding factor requires very careful design if it is to be avoided.

When some experts were contacted with regards to reducing the noise level, most agreed that some of the available methods would work on the drill transmissions. They also indicated that, without doing some experimenting, there was no way to put actual figures on the amount of gain available.

For this reason it will be necessary to underto a gradual improvement, first using the existing housing and trying better gears and then, if necessary, designing a complete new gear box. It may also be possible to incorporate noise enclosures but this will be made difficult by the need for accessibility and cooling.

TABLE 8.1

DRIVE NOISE REDUCTION METHODS

METHOD	RESULT
USE HELICAL CUT	MORE UNIFORM MESHING
IMPROVE KINEMATIC ACCURACY	MORE UNIFORM MESHING
INCREASE CONTACT RATIO	REDUCE DYNAMIC LOAD
USE NON-METALLIC GEAR MATERIAL	REDUCE NOISE TRANSMISSION
REDUCE PITCH LINE VELOCITY	REDUCE DYNAMIC LOADS
STIFFEN SHAFTING	IMPROVE TOOTH ALIGNMENT INCREASE LIFE
CONTROL BACKLASH	REDUCE NOISE DURING LOW LOAD
GEAR MESH PHASING	REDUCE NOISE BY CANCELLATION
REDUCE HOUSING DYNAMIC RESPONSE	DEADEN NOISE TRANSMISSION
BLANKET, BARRIER OR ENCLOSURE	CONTAIN NOISE
PROVIDE VIBRATION ISOLATION BETWEEN GEAR AND SHAFT	REDUCE STRUCTURE-BORN NOISE

9.0 NOTES ON REGULATIONS

Diamond drillers will normally be bound by Provincial Regulations laid down by respective Departments of Labour or Workmen's Compensation Boards. Exceptions would include drilling carried out underground or on the property of an operating mine, which would come under the jurisdiction of the local mining act, or drilling carried out for the Federal Government, which would come under the Federal Regulations. Noise regulations are usually the same between regulating bodies within a given province, but do vary between provinces, as indicated by the attached summary (Table 9.1). Regulations are constantly under review, so it is always advisable to check for possible revisions before undertaking any major work which could be affected by the prevailing laws. However, a few trends have become apparent over the past few years and are discussed below.

The first obvious trend, which can be seen in Table 9.1, is that all the provinces are lowering the allowable eight hour limit of continuous noise exposure to 85 dBA. Impulse noise will not usually be a concern for diamond drillers. As of June 12, 1980, half the provinces had adopted this limit and the others remained at 90 dBA. Whether the permitted noise level is likely to be regulated below 85 dBA in the future cannot be determined with certainty. However, it is not probable, since Canadian regulations generally follow the lead of the United States and the United States, after six years of debate,* have recently decided to hold their permissible level at 85 dBA.

Although noise regulations have been in effect in most provinces since the early to mid 1970's, enforcement of the regulations has been lax to date. This laxity is in the process of changing as evidenced by the passing of Bill 17 in Quebec, Bill 70 in Ontario,

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* The Bureau of National Affairs Inc
Noise Regulation Reporter, January 14, 1981

TABLE 9.1 CURRENT OCCUPATIONAL NOISE REGULATIONS OF WIDE APPLICATION IN CANADIAN PROVINCES (JUNE 12, 1980)

JURISDICTION	STEADY-STATE NOISE			IMPULSE NOISE	
	MAXIMUM PERMISSIBLE DAILY 8 HOUR TWA EXPOSURE LEVEL (dBA)	TIME/INTENSITY DOUBLING RATE dBA	MAXIMUM PERMISSIBLE LEVEL WITHOUT HEARING PROTECTION (dBA)	MAXIMUM PERMISSIBLE LEVEL (dB PEAK SPL) PER PERMISSIBLE NUMBER OF IMPULSES PER DAY	RATE OF INCREASE (6)
TREASURY BOARD	90	5	115	140 (3)*	(7)*
ALBERTA	85	5	115	140 (3)*	(7)*
BR COLUMBIA	90	3	105	140/90	10
MANITOBA (1)	85	5	115	140/100	10
N BRUNSWICK	90	5	115	140/100 (4)*	10
NEWFOUNDLAND	85	5	115	140/100	10
NOVA SCOTIA	85	5	115	140/100	10
ONTARIO	90	5	115	(5)*	
QUEBEC	90	5	115	140/100	10
SASKATCHEWAN (8)*			85	(5)*	
P E I (2)*					

( )* Refer to TABLE 9.1 NOTES

TABLE 9.1

NOTES

1. No permissible noise levels are specified in the legislation but are to be determined by the responsible branch or division within the Department of Labour. Currently, the threshold limit values (TLV) of the American Conference of Governmental and Industrial Hygienists (ACGIH) are adopted for this purpose.

2. No other provision than that "noise levels in places of employment shall be kept within a range which is comfortable and harmless to employees".

3. No provision on the permissible number of impulses of 140 dB peak SPL.

4. The level of impulse noise is given in dBA, obviously by mistake.

5. No provision on impulse noises.

6. Rate of increase of number of impulses for each 10 dB increase in the peak SPL of the impulse.

7. No provision on the interrelation between the permissible number and the peak SPL of the impulse.

8. Permissible noise levels are not specified in the legislation, but are to be determined by the responsible branch within the Department of Labour. TWA concept is not adopted for steady-state noise.

and the hiring of inspectors by the Workers' Compensation Board in British Columbia. It is fairly certain that these provinces will soon adopt the current U S Occupational Health and Safety Administration practice of citing industry for violations of noise regulations and fining those unwilling to undertake the necessary corrective action. Other provinces will probably follow suit in time.

Wise industries have taken advantage of the grace period to develop noise control methods for noisy equipment with no "off the shelf" solutions. This avoids a potential problem of having to spend money on inappropriate noise control equipment in order to comply with government citation deadlines, and then having to go back and spend more money searching for the correct solution.

Industries who have been slow getting started can still avoid this type of confrontation with authorities provided that they can prove they have a program underway which will deal with existing noise problems. At the moment at least, a sincere intent to comply with the spirit of the law will usually avoid the imposition of a deadline for resolving noise problems which require some development work. However, compliance deadlines may be imposed where proven noise control methods are known to exist.

In summary, both noise regulations and the methods in which they are applied across Canada are in a state of flux. However, it is certain that currently noisy operating equipment will be silenced in the future - by force, if not by choice. Original equipment manufacturers in Europe and the United States who were forced to live with noise regulations ten years ago, already have a head start on producing quieter-operating equipment lines. These products will have an increasingly larger impact in the Canadian marketplace if Canadian manufacturers do not start developing competitive products.

APPENDIX I

STATEMENT OF WORK:

1. It has been established that the overall noise level of diamond drilling equipment is the composite of several individual major sources. It has also been established that even by totally eliminating one of of these (say the power source), the residual noise level will still exceed the legal limit set by provincial authorities. Moreover it is now known that the contribution of major noise sources must be determined in the field under actual operating conditions, and not merely under laboratory conditions.

   Rather than concentrating on reducing the noise level of any one known source at this point, the contractor shall undertake a series of tests to determine the individual noise levels contributed by all major sources (such as gear trains, drilling head, accessories, prime movers, etc.) under both shop and actual operating conditions.

   All major groups of diamond drilling equipment currently used in Canada, including diesel and pneumatic power sources, mechanical and hydraulic drill designs, at both above - and underground locations, shall be examined.

2. After establishing the individual contributions of the standard diamond drill components, the contractor shall examine the best steps (both on theoretical and practical grounds) that may be taken, to dampen these noise levels. Any work done by others in this field should also be examined and evaluated.

3. Wherever special noise reducing modifications have already been developed the contractor shall study their adaptability to diamond drilling requirements and, wherever possible, undertake the necessary modifications.

   "The Silent Power System" developed by Hatz diesels, the special muffler developed by INCO at Thompson, Manitoba, and the muffled drill design of Canadian Longyear (with power source removed to large distances) should be given special attention.

4. The contractor shall undertake noise level measurements with as many of the specially developed noise suppression equipment (point 3) as can be adapted to diamond drilling.

   These measurements shall be taken both under shop and actual operating conditions.

5. The contractor shall evaluate the results of the foregoing measurements (point 4). Wherever further improvements are feasible, these should be examined and executed.

6. The contractor shall submit a carefully reasoned proposal for recommended future work in area of interest, including both time and cost estimates.

   The requested proposal should include a cost estimate and time schedule itemized along the lines detailed in the section on "Statement of Work".

APPENDIX II

State Industries Limited manufactures a polyurethane muffler for use on both stopers and diamond drills. The present device for diamond drills is sized for a CP-65.

State Industries Limited
1104 Wall Street
Winnipeg, Manitoba
R3E 2R9

Budd (Canada) Incorporated manufacture a muffler sold under the trade name (Cowl).

Osborne & Malucz
P O Box 962
Winnipeg, Manitoba
R3C 2V3

82-40 M.U. Savich

Abatement of noise and vibration in the Canadian mining industry

1982

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Borba protiv buke i vibracija u Kanadskoj rudarskoj industriji

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ATTÉNUATION DU BRUIT ET DES VIBRATIONS DANS L'INDUSTRIE MINIÈRE CANADIENNE

par

M.U. Savich*

RÉSUMÉ

ABRÉGÉ :

Le Canada est l'un des premiers producteurs mondiaux de minéraux et de combustibles minéraux. Les méthodes de production font intervenir de grosses machines puissantes qui ont fait augmenter les niveaux du bruit et des vibrations au-delà des limites jugées acceptables dans les normes et les règlements existants et proposés. Des mesures organisées ont été prises dans l'industrie minière canadienne pour lutter contre le bruit et les vibrations. Selon des données statistiques, le nombre de pensions versées pour surdité causée par le bruit industriel a atteint un niveau sans précédent en 1977-1978 au Canada. Les mesures adoptées ont produit des résultats positifs. Le Canada doit relever les nouveaux défis d'augmenter la production et la productivité minières et d'améliorer l'environnement minier par l'utilisation de machines à fonctions électroniques intelligentes.

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Le Canada se situe au troisième rang dans le monde pour la production de minéraux et de combustibles minéraux. En 1979, la participation des quelques 90 000 travailleurs de l'industrie minière au produit national brut s'est élevée à 26 milliards de dollars, soit 10 %. Parmi ces travailleurs, 22 500 ou 25 % sont exposés à un bruit dépassant 90 dBA par jour de huit heures et 18 000 ou 80 % d'entre eux sont exposés à un bruit dépassant 80 dBA par jour de huit heures. Pour accroître la production, des efforts considérables ont été consacrés à la mécanisation, à l'optimisation de la vitesse de foration, à la mise au point de méthodes minières, à l'élaboration de méthodes sûres, etc. Ces efforts se sont toutefois traduits par une augmentation des effets du bruit et des vibrations sur le travailleur de l'industrie minière canadienne. Des niveaux de bruit trop élevés dans l'industrie minière causeraient une perte en audition chez certains travailleurs. Les effets de la vibration sur les ouvriers des mines et des usines n'ont pas encore été définis avec exactitude en raison du manque de normes dans ce domaine. Au cours de la grande révolution industrielle, chaque progrès technologique s'est traduit par une production considérablement accrue de minéraux et de combustibles minéraux. Cette production accrue a nécessité la mise au point de gros engins puissants, plus bruyants et plus vibrants. C'est pourquoi des règlements et des normes sur le bruit et les vibrations ont été adoptés pour déterminer des limites acceptables d'exposition pour les travailleurs.

Les lignes directrices actuellement en vigueur au Canada sont celles adoptées par l'OSHA. La Colombie-Britannique est la seule province à appliquer la norme ISO R 1999. La proposition ISA DIS 5399 de l'Organisation internationale de normalisation est actuellement utilisée pour mesurer les vibrations transmises aux mains. Des mesures des vibrations globales du corps ont été comparées avec celles prescrites dans la norme ISO 2631. Les progrès accomplis actuellement dans l'industrie minière attestent des avantages à recourir à la méthode décentralisée pour lutter contre le bruit et les vibrations.

Les fortes ondes sonores produites par des machines à percussion et des chargeuses-transporteuses qui frappent l'oreille directement peuvent causer une surdité temporaire ou permanente. Les vibrations, particulièrement les vibrations transmises aux mains par des perforatrices pneumatiques, ont été mentionnées comme un danger possible à la santé des travailleurs.

Les solutions au problème du bruit et des vibrations porteront sur la source, le trajet et le récepteur. La modification du trajet est l'une des principales méthodes de protection contre le bruit et les vibrations. Les fabricants canadiens d'équipements et d'outils miniers tentent de diminuer le plus possible les niveaux de bruit et de vibrations. Dans certaines mines, on utilise depuis quelques temps des appareils commandés à distance. Ces appareils ont permis aux travailleurs de s'éloigner des sources de bruit et de vibrations. Le Canada se dirige rapidement vers la mécanisation complète étant donné que la production doit augmenter pour répondre aux besoins économiques et environnementaux. Il faudra indéniablement recourir à des machines robotisées pour augmenter la production.

Il y a plus de dix ans, les travaux poussés effectués dans des mines canadiennes commencaient par la protection du personnel et des examens audiométriques. Actuellement, les examens audiométriques sont obligatoires dans toutes les mines canadiennes. Il est obligatoire pour les futurs employés de subir ces examens. Des données statistiques montrent que les mesures de lutte mises en oeuvre ont donné des résultats. Le nombre de pensions versées aux travailleurs canadiens devenus sourds après exposition au bruit industriel a atteint un niveau sans précédent en 1977-1978.

L'industrie canadienne doit relever un nouveau défi depuis la récente révolution technologique qui consiste à recourir à des machines à fonctions électroniques intelligentes pour augmenter la production et la productivité et pour améliorer l'environnement dans son ensemble. Le Canada possède les dimensions d'un continent avec de vastes différences régionales sur le plan du climat, de la démographie et des matières brutes; il doit pour cette raison, avec l'aide de la technologie moderne, exercer une maîtrise sur l'espace et le temps.

ABATEMENT OF NOISE AND VIBRATION IN THE CANADIAN MINING INDUSTRY

by

M.U. Savich*

ABSTRACT

SUMMARY:

Canada is a world leader in the production of minerals and mineral fuels. Production methods utilize large and powerful machines which have increased levels of noise and vibration above the acceptable limits of existing and proposed regulations and standards. An organized effort has been initiated in the Canadian mining industry to control noise and vibration. Statistical data show that the number of pensions awarded for industrial noise deafness reached a peak level in 1977-78 in Canada. The adopted measures have produced positive results. Canada today faces the new challenge of increasing production and productivity and control of the mine environment through the use of electronic intelligence functions of machines.

Canada ranks third in the world in the production of minerals and mineral fuels. In 1979 some 90 thousand workers in the mining industry contributed 26 billion dollars which represents ten percent of the gross national product. Of those employed in the mining industry 22,500 or 25 per cent are exposed to noise in excess of 90 dBA per eight-hour day and 18,000 or 20 percent are exposed to noise in excess of 80 dBA per eight-hour day. To achieve high production levels, great effort has been put into mechanization, optimizing drilling speed, developing mining methods, safety procedures, etc. The result is that noise and vibration effects upon the workman in the Canadian mining industry are increasing. Excessive noise levels in the mining industry are alleged to cause hearing loss in workers. The effects of vibration on workers in mines and mills have not been accurately defined, due to insufficient standards. In the great industrial revolution each technological revolution resulted in greatly increased production of minerals and mineral fuels.

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* Research Scientist, Elliot Lake Laboratory, CANMET, Energy, Mines and Resources Canada, Elliot Lake, Ontario, Canada.

Increasing production required the introduction of large and powerful machinery which resulted in increased noise and vibration. This has resulted in the adoption of noise and vibration regulations and standards to create acceptable limits for the workers exposure.

The guidelines presently in use in Canada are those adopted by the OSHA. Only British Columbia uses Standard ISO R 1999. International Standard Organization's draft proposal ISA DIS 5399 is currently used for the measurement of hand transmitted vibration. Whole body measurements have been compared with the standard prescribed by ISO 2631. Current progress in the mining industry has demonstrated the value of the decentralized approach to noise and vibration control.

Powerful sound waves from percussive machines and load-haul-dump (LHD) equipment directly striking the ear can cause temporary deafness or permanent deafness. Vibration, and particularly localized vibration of the hand due to pneumatic rock drills has been cited as a potential hazard.

Solutions to the noise and vibration problem will be concerned with the source, the path and the receiver. Path modification is one of the major methods of protection from noise and vibration. Canadian manufacturers of mining equipment and tools endeavour to reduce the noise and the vibration levels to the minimum possible. Remote control devices have been introduced to mines in recent times. These devices have removed the workman from the sources of noise and vibration: Canada will move rapidly towards full mechanization as production must increase to meet economic and environmental pressure. The need for implementation and robotic machines is undeniable to achieve increased production.

Over ten years ago intensive work in Canadian mines began on personal protection and audiometric tests. Presently audiometric testing is mandatory in all Canadian mines. Pre-employment tests are obligatory. Statistical data have shown that control measures implemented have produced results. The number of pensions awarded for industrial noise deafness in Canada reached a peak level in 1977-78.

Canadian industry faces a new challenge with the recent technological revolution, the utilization of electronic intelligence functions of machines to increase production and productivity and to improve the total environment. Canada has the dimensions of a continent with vast regional differences in climate, demography and raw materials and because of this must, with modern technology, control space and time.

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INTRODUCTION

In the production of minerals and mineral fuels Canada ranks third in the world, with product value of 26 billion dollars (1979 figures*) which represents ten percent of the gross national product. Ninety thousand workers in mines and mills contributed this income. Over the last 20 years great effort has been directed into mine mechanization, development of mining methods, optimization of drill speeds, safety programs, etc., and simultaneously, to produce environmental conditions in compliance with permissible levels.

Noise is encountered by the employee primarily in the work place where 25 percent (22,500) are exposed to levels in excess of 90 dBA per eight hour shift and 20 percent (18,000) to levels in excess of 80 dBA. Excessive levels of noise in the mining industry are alleged to cause hearing loss in workers, as well as adversely affecting their safety, health and productivity. This is the reason why the problem of noise and vibration attracts so much concern in the Canadian mining industry.

TECHNOLOGY, POLLUTION AND POPULATION GROWTH

The industrial revolution in introducing machinery to the mining industry also introduced a serious health hazard, noise and vibration. Vibration effects in the form of "miner's white finger disease" was probably first noticed on the earliest miners of the Neolothic Age before 6,000 BC (Fig. 1). It took hard work with stone hammers to win copper from Precambrian Keweenawan conglomerate (1,2,3). From this time to the discovery of dynamite (1876) advances in mining technology were developed very slowly. It took

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* The figures presented are based on 1979 production which reflect market values before the price increases of gold and fuel.

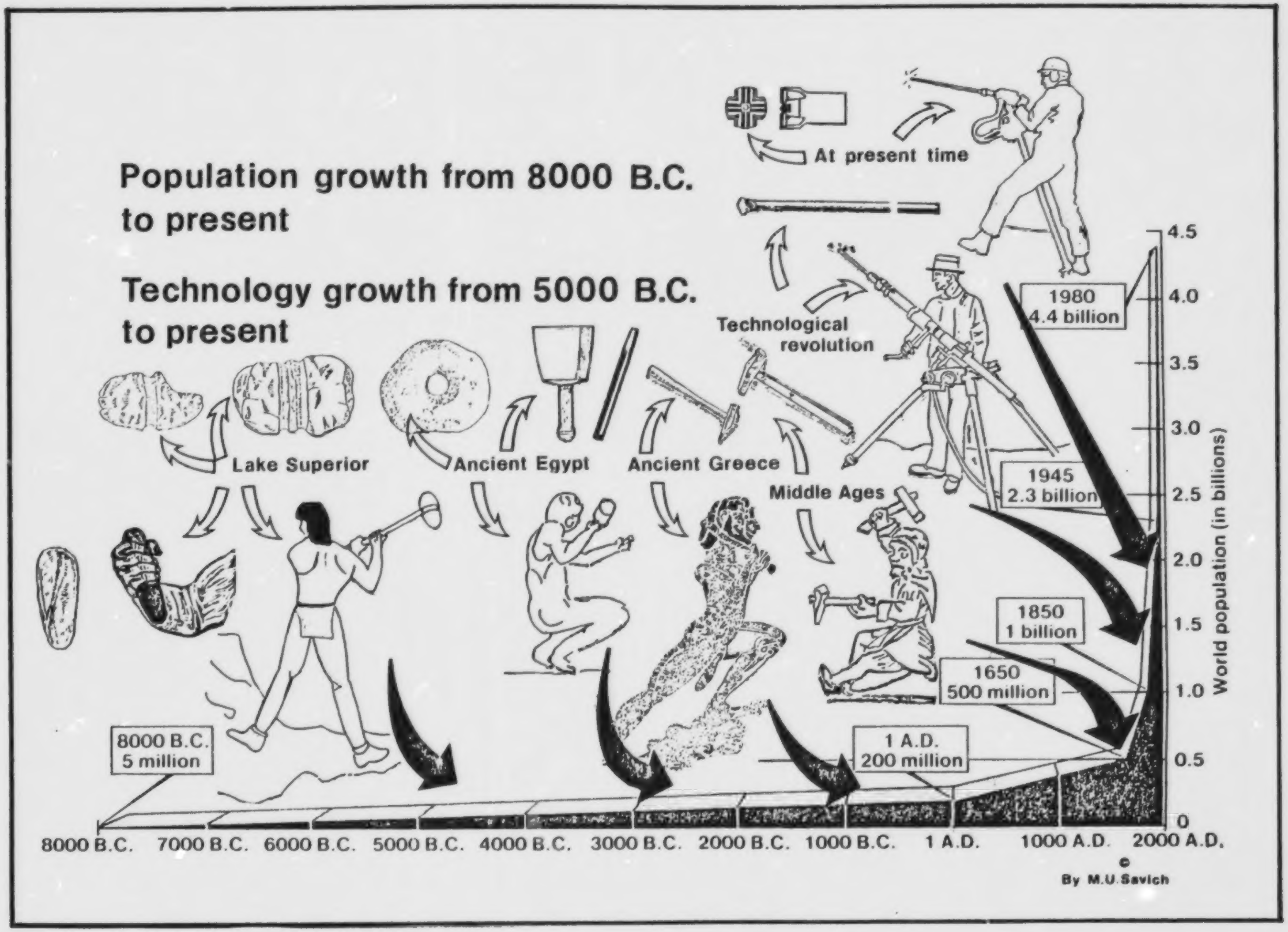


Fig. 1 - Mining technology from the Stone Age to present.

3,000 years before miners at Timna, a mine of Ancient Egypt, placed a hole through the stone heads of their hammers and so eased their labours and increased productivity (Fig. 1) (5). During the great industrial revolution the mining industry was rapidly developed. Within the industrial revolution there were several technical revolutions:

- The invention of the steam engine by James Watt (1769) and its first application to mine pumps in Cornwall (1789) solved the problem of dewatering and returned these mines to production (6);
- The gas motor, developed for the manufacture of vehicles in 1889 using Gottlieb Daimler's patents, was used extensively in new mining machinery in conjunction with compressed air (6);
- Electricity first generated at Niagara Falls by Nikola Tesla in 1896 became a force without which it would be impossible to imagine modern mining (7);
- Discovery of nuclear fission, the controlled chain reaction achieved by Enrico Fermi in 1942, provided a new source of energy which could be transformed into electricity (6).

Enormous population growth followed the technological revolution as advances were made in all fields Man became nature's master with his advanced technology and required increased production of raw materials and food to satisfy the needs of a growing population. Environmental problems, a consequence of this need for increased production, were created by man himself (Fig. 2). Deafness caused by industrial noise was recognized as an industrial disease.

Immediately following the second World War, action was taken against noise. The battle against vibration is a more recent development. It became immediately obvious that the most effective approach was for each location to address their own noise and vibration problems individually.

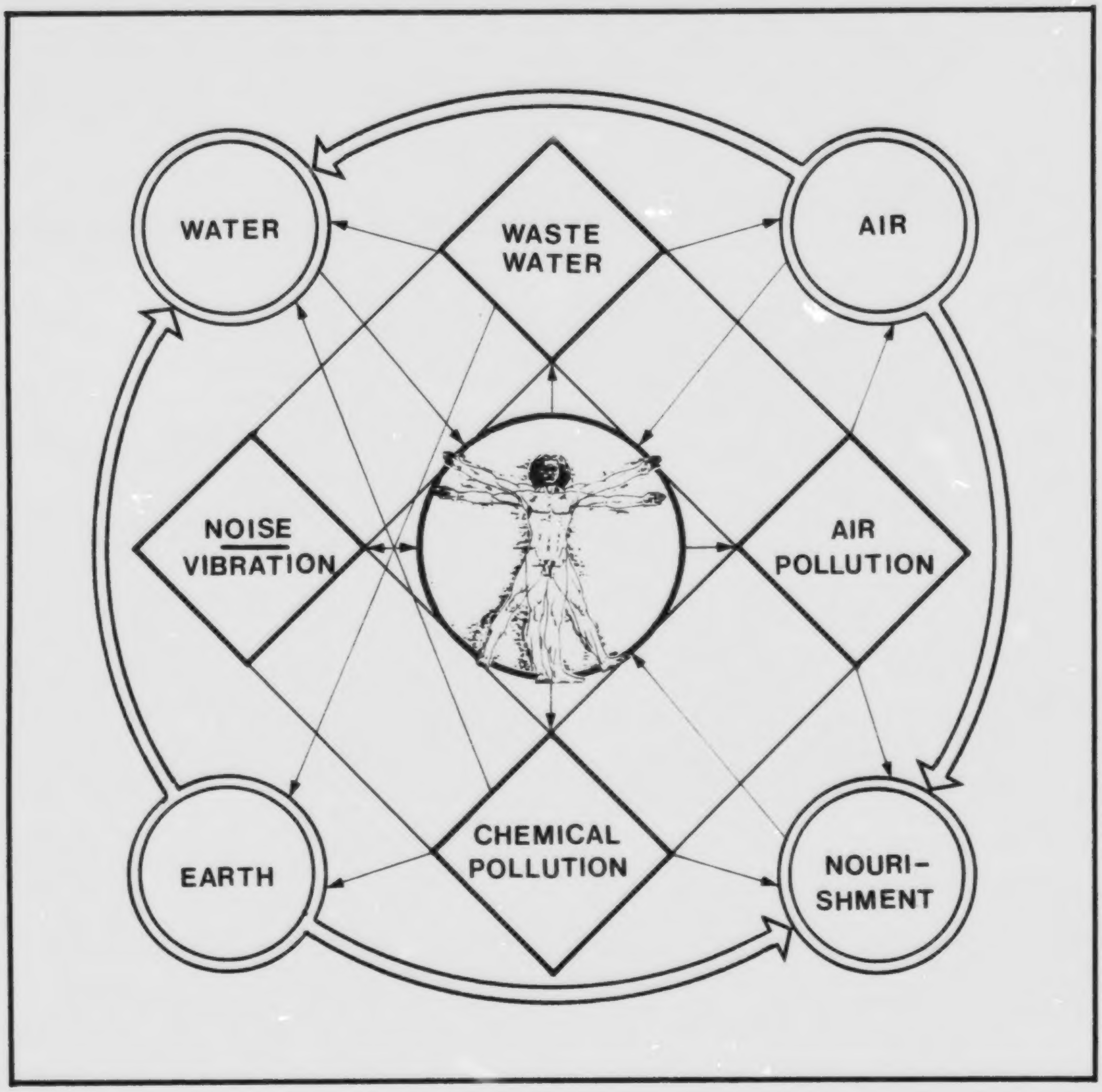

WATER
WASTE WATER
AIR
NOISE VIBRATION
AIR POLLUTION
EARTH
CHEMICAL POLLUTION
NOURI-SHMENT

Fig. 2 - Man and his environment.

NOISE AND VIBRATION REGULATIONS AND STANDARDS

Generally speaking, the Federal Government assumes responsibility in noise and vibration for matters affecting transportation (marine, rail and air), national health and welfare, and trade and commerce. The Provinces have jurisdiction over all matters of a local or private nature, the result being that each Province has enacted legislation to suit their own requirements (Fig. 3). The guidelines presently used in Canada, excepting British Columbia, are those adopted by the OSHA*, for example, which permit a worker to be exposed to a noise level of 90 dBA for 8 h/day and require dividing in half the permissible exposure time for each 5 dBA increase in noise level. British Columbia has an exchange rate of 3 dB increase for halving of duration (ISO R 1999). Although many countries have introduced vibration standards specifying acceptable limits for hand-transmitted vibration, there is no standard applicable to workers in the Canadian mining industry (8). There is, however, an International Standards Organization draft proposal (ISO DIS 5349). Mining workers are also exposed to whole-body vibration. Measurements have been compared with the standard prescribed by ISO 2631.

Standards Council of Canada (SCC), a Federal Crown Corporation which reports to Parliament through the Ministry of Industry, Trade and Commerce, has indirect noise control interests. Standards, once written by the Canadian Standards Association (CSA) are reviewed by SCC to ensure that standards writing criteria are met. The CSA has a committee working on acoustics, noise and vibration control focusing on standards with respect to:

1. Measurement methods and instrumentation;
2. Noise from powered equipment;
3. Noise from transport vehicles;

---

* The Occupational Safety and Health Act.

CANADA
Alaska (U.S.A.)
YT
NWT
BC
Alta.
Sask.
Man.
Ont.
Que.
Nfld
PEI
N.B.
N.S.
U.S.A.

5 dB Exchange Rate	Permissible Hours per Day												3 dB Exchange Rate
Level in dBA (OSHA*)	Newfoundland	Nova Scotia	Manitoba	Alberta	New Brunswick	Quebec	Prince Edward Island	Ontario	Saskatchewan	Yukon	N.W. Territories	British Columbia	Level in dBA (ISO++)
80	16				-	-	-					16	87
85	8				-	-	-					8	90
90	4				8	8	8					4	93
95	2				4	4	4					2	96
100	1				2	2	2					1	99
105	0.5				0.5	1	1					0.5	102
110	0.25				0.25	0.5	0.5					0.25	105
115	0.125				0	0	0.25					0	10[illegible]

OSHA Lowering ▶

OSHA Modification ▶

OSHA ▶

◀ISO

NOTE: *OSHA - The Occupational Safety and Health Act.
++ISO - The International Organization for Standarization (ISO R 1999).

Fig. 3 - Noise regulations in Canada.

4. Industrial noise;
5. Noise from small appliances;
6. Building acoustics;
7. Hearing measurement.

A committee includes representatives from industry, the Federal and Provincial Government Departments, Universities and consumer organizations. The National Research Council of Canada (NRCC) has its main influence on Canadian standards and regulations directly, and through American standard and professional associations indirectly.

NOISE AND VIBRATION CONTROLS IN MINES

Each country faces a different set of problems and values in noise and vibration controls in mines. The following lines could be considered as the basis for the noise and vibration controls in Canadian mines:

1. A massive influx of new employees entering the mining work force must be better protected and educated;
2. We have met the challenges of inflation by organization and a new increase of productivity in Canadian mines;
3. This testing will be used by the manufacturers of new and special mining machinery over the next decade for both the domestic and foreign markets (9).

Mining Research Centre, Canada Centre for Mineral and Energy Technology (CANMET), Energy, Mines and Resources Canada has organized its work to solve these requirements, so that mines, without great effort and high cost of compliance, can meet the specified goals.

Over ten years ago, intensive work in Canadian mines began on personal protection and audiometric tests (10). Noise measurements have become frequent. CANMET's techniques and experience were transferred to Canadian mines through publications, or assistance in measurements.

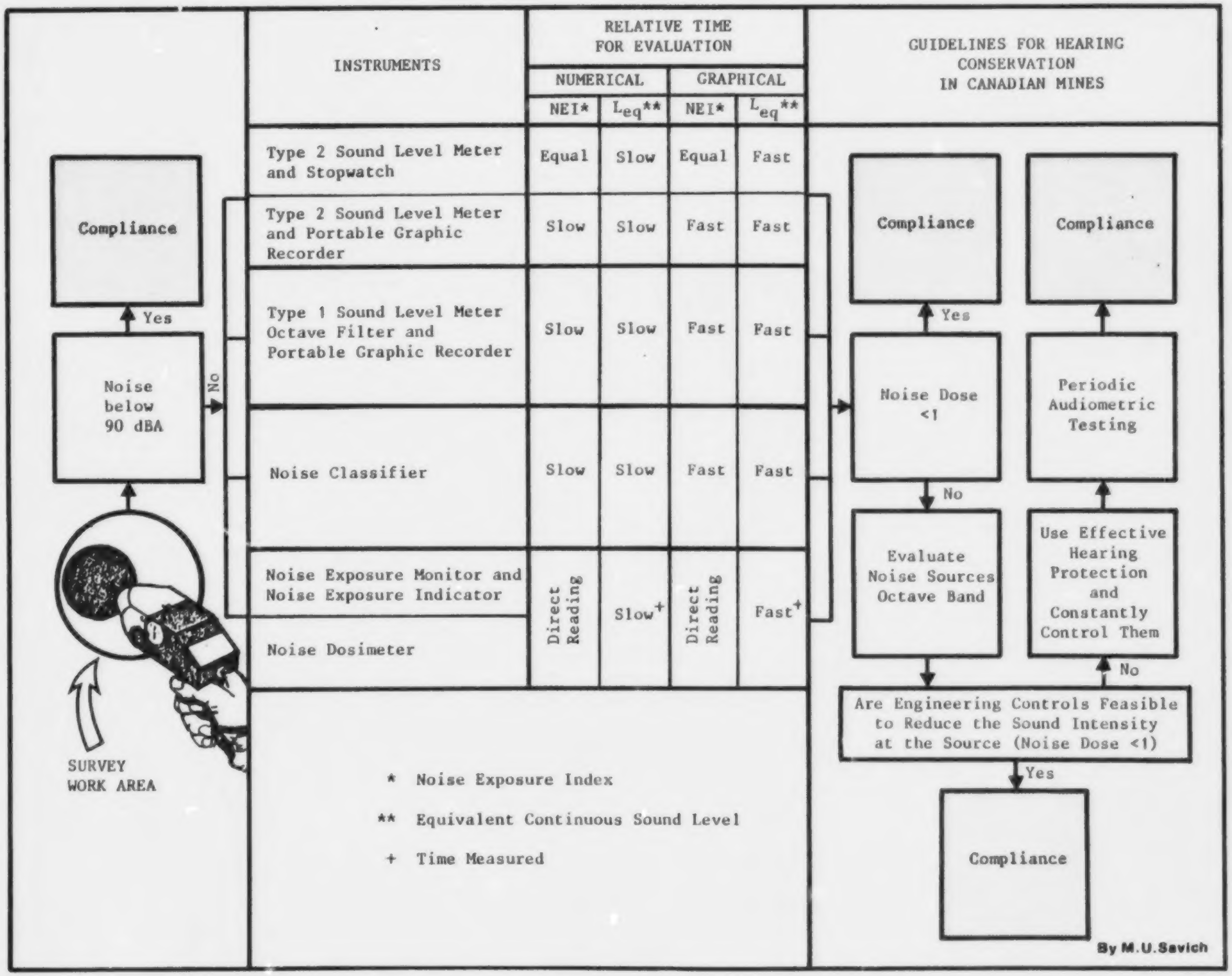
The basic instruments used in mines for measuring noise and the noise exposure index are given in Fig. 4. CANMET has developed a graphical evaluation method which has reduced the probability of error and the time required by a factor of ten or more as compared to a numerical method (11). The main effort is now being made in dosimetry. It is believed that therein lies the future of noise exposure index measurements in mines. The noise monitor hat has presented the main stand of CANMET research effort, moving forward automated, reliable and safe environment system in mines which will enable highly accurate results to be obtained (12,13). The new generation of dosimeters automatically gives all statistical data, and integrates the amplitude distribution histogram and level (L_{OSHA}) versus time (s) graph. The aims of the noise exposure index measurements are outlined in Fig. 5 under two general headings (14):

1. Partial information of NEI measurement for the worker, union and safety office;
2. Full information of NEI measurement for management, union and environmental office directly.

The system of measurement has a twofold purpose:

a) to protect the hearing of the worker; and
b) to increase productivity.

The system exemplifies the important role of the computer program. The computer could even write the report. Management will be able to follow up on work efficiency, maintenance and production. The full completion of this project undoubtedly represents an important, as well as historical, milestone.


Compliance
Yes
Noise below 90 dBA
No
SURVEY WORK AREA
GUIDELINES FOR HEARING CONSERVATION IN CANADIAN MINES
Compliance
Yes
Noise Dose <1
No
Evaluate Noise Sources Octave Band
Are Engineering Controls Feasible to Reduce the Sound Intensity at the Source (Noise Dose <1)
Yes
Compliance
No
Use Effective Hearing Protection and Constantly Control Them
Periodic Audiometric Testing
Compliance
By M.U.Savich

INSTRUMENTS	RELATIVE TIME FOR EVALUATION			
	NUMERICAL		GRAPHICAL	
	NEI*	L_{eq}**	NEI*	L_{eq}**
Type 2 Sound Level Meter and Stopwatch	Equal	Slow	Equal	Fast
Type 2 Sound Level Meter and Portable Graphic Recorder	Slow	Slow	Fast	Fast
Type 1 Sound Level Meter Octave Filter and Portable Graphic Recorder	Slow	Slow	Fast	Fast
Noise Classifier	Slow	Slow	Fast	Fast
Noise Exposure Monitor and Noise Exposure Indicator Noise Dosimeter	Direct Reading	Slow+	Direct Reading	Fast+

* Noise Exposure Index

** Equivalent Continuous Sound Level

+ Time Measured

Fig. 4 - Noise measurement procedure and instrumentation used for noise dose measurement in mines.

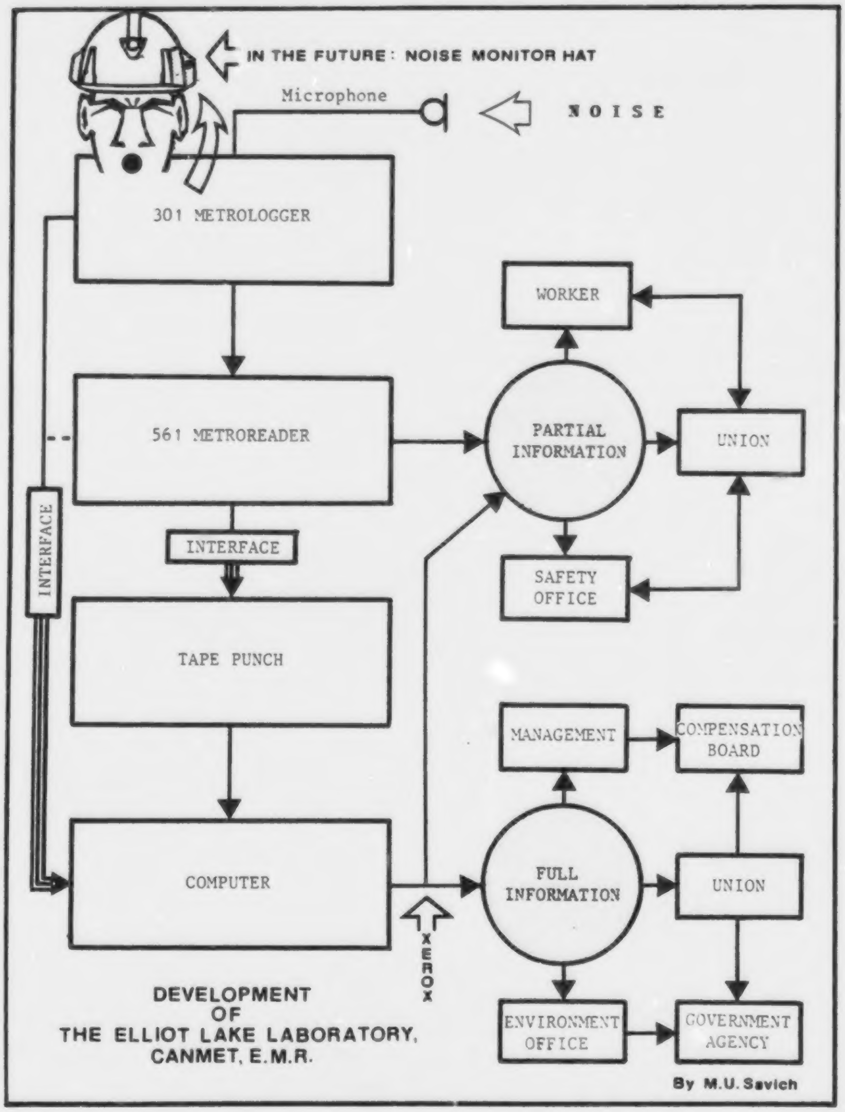

IN THE FUTURE: NOISE MONITOR HAT
Microphone
NOISE
301 METROLOGGER
561 METROREADER
INTERFACE
INTERFACE
TAPE PUNCH
COMPUTER
XEROX
WORKER
PARTIAL INFORMATION
UNION
SAFETY OFFICE
MANAGEMENT
COMPENSATION BOARD
FULL INFORMATION
UNION
ENVIRONMENT OFFICE
GOVERNMENT AGENCY
DEVELOPMENT OF THE ELLIOT LAKE LABORATORY, CANMET, E.M.R.
By M.U. Savich

Fig. 5 - Flow sheet diagram of Noise Exposure Index test procedure.

ENGINEERING CONTROLS

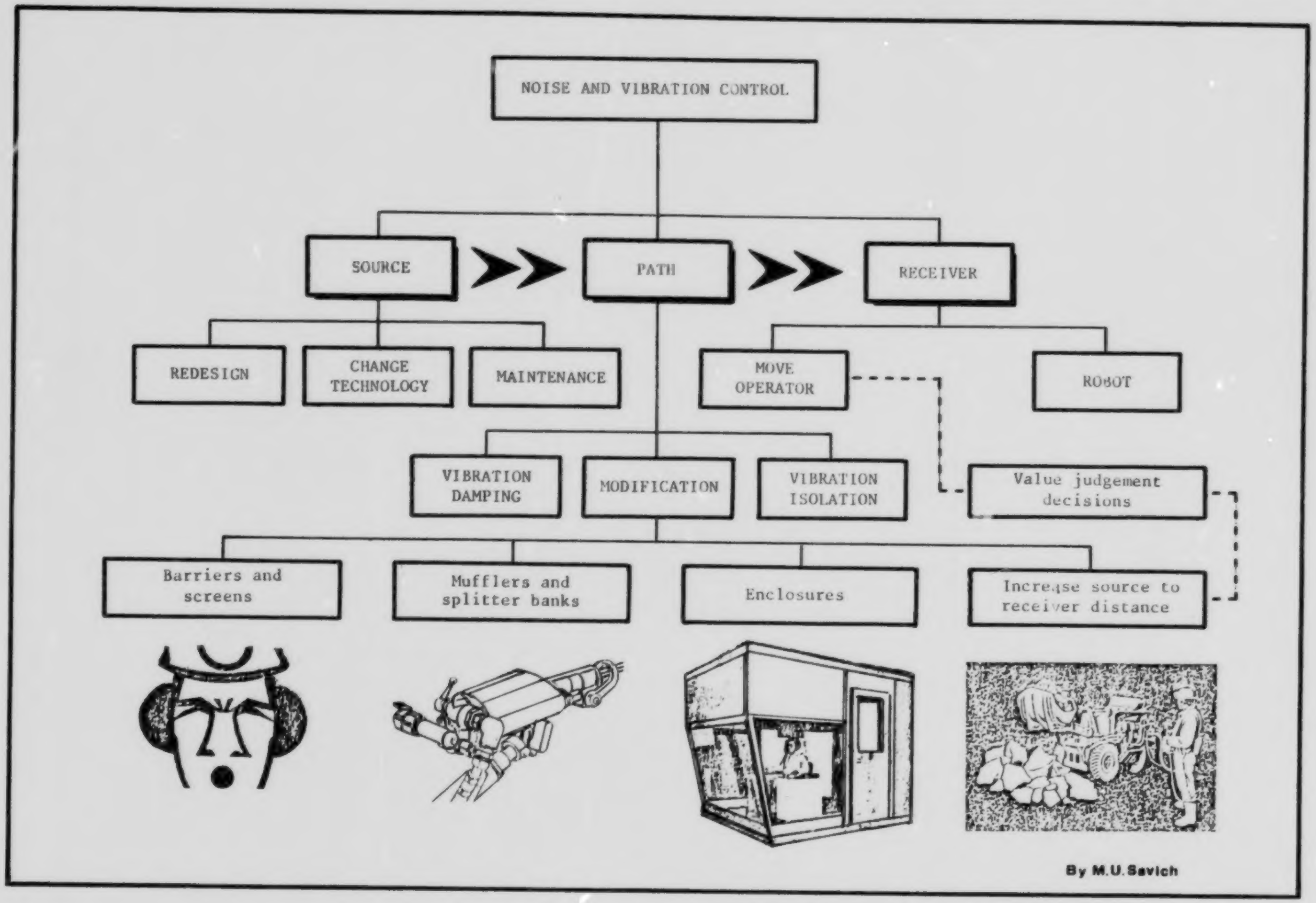
Significant progress towards higher productivity has been achieved through mechanization, through improved mining methods and through better design of mining machinery and equipment. Continuous operation of machinery has increased the levels of noise and vibration in mines. Powerful sound waves from percussive machines and load-haul-dump (LHD) equipment directly striking the ear can cause temporary deafness. The ability to hear high-frequency sound is lost first and later, the lower frequencies involving speech are affected and the operator may completely lose his ability to understand the speech of others. Vibration, and particularly localized vibration of the hand due to powerful pneumatic rock drills, has been cited as a potential hazard. Finally, it should be repeated that the International Standards Organization is developing a vibration standard at this time. Clearly, it behooves any Canadian manufacturer of hand-held pneumatic tools to attempt to reduce the vibration level to the minimum possible.

Solutions to the noise and vibration problem will be concerned with (Fig. 6):

1. The noise and vibration source;
2. The path of sound and vibration propagation; and
3. The receiver.

Redesign of machines to reduce self-generated noise and vibration or the design of a new machine (change in technology) is a long term job. A change in technology also changes the economic factors of production and productivity. With the current energy crisis it is difficult to expect that this approach is acceptable.

Path modification is one of the major methods of protection from noise and vibration available with today's mining technology. Ear protectors


NOISE AND VIBRATION CONTROL
SOURCE
PATH
RECEIVER
REDESIGN
CHANGE TECHNOLOGY
MAINTENANCE
MOVE OPERATOR
ROBOT
VIBRATION DAMPING
MODIFICATION
VIBRATION ISOLATION
Value judgement decisions
Barriers and screens
Mufflers and splitter banks
Enclosures
Increase source to receiver distance

By M.U.Savich

Fig. 6 - Basic elements of a noise abatement program in the Canadian mining industry.

are a basic form of protection. The first hearing protectors made of impregnated cotton were used in Canadian mines in 1952. Ear protectors are capable of reducing noise levels by 10 to 45 dB. In Canadian mines the use of ear protectors is mandatory. Fifty percent of noise exposed workers use ear muffs, forty percent ear plugs and three percent ear muffs and ear plugs (15). Helmets are not significantly better than ear muffs with respect to attenuation and cost (16). Measurements show that ear muffs have poor attenuation in the working condition, only about 13 dBA. Modification to the path by enclosing either the man or the machine can provide an adequate solution to a noise problem with 21 dBA of attenuation (Fig. 6). The noise levels inside the cabs of heavy-duty mining vehicles of 125 hp and above present a serious occupational hazard for their operators (17). Sheet lead, combined with fibreglass for added fire protection, is also being used on underground and open pit mining equipment for sound attentuation purposes. Tests comparing the noise levels of an untreated cab with the foam-lead-foam treated cab reveal a 17 dBA noise reduction.

The noise in mines is mostly associated with rock drills and creates a potentially hazardous acoustical environment. Rock drills, the worst offenders, have been improved by the successful application of devices such as lead-off hoses on the exhaust,and reactive mufflers, the development of which has been the result of long and careful research programs in Canada (Fig. 6 and 7). Absorptive mufflers incorporating parallel baffles are usually applied to noise control of equipment, such as centrifugal compressors, fans and gas turbines.

Interest in noise abatement and development of control methods are not the province of professional researchers alone. Mr. T. Coté at Gaspé Copper Mines designed a method of preventing the air from escaping during

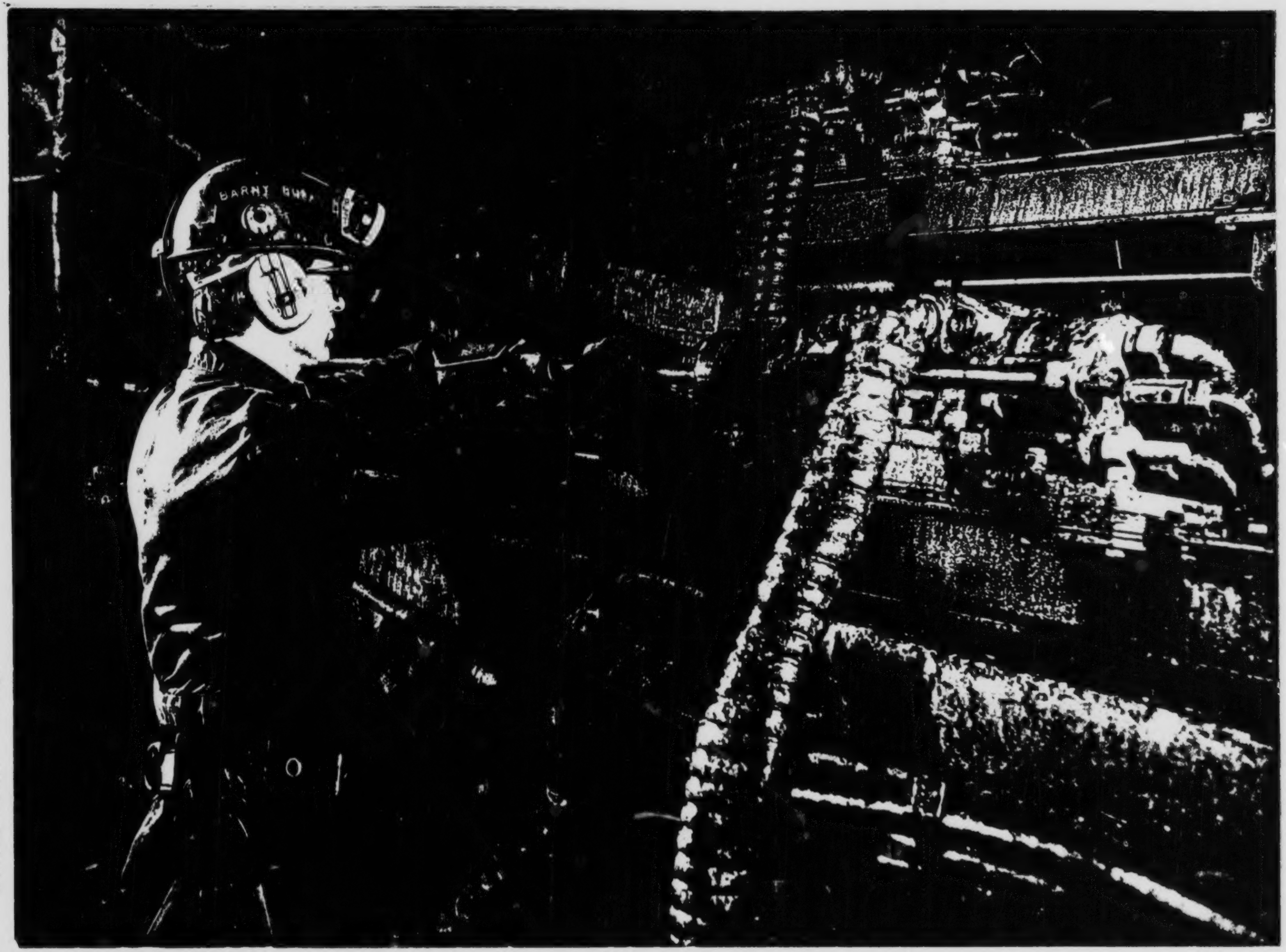


Photo: INCO METALS

Fig. 7 - A total environment in Canadian mines: silencing of exhaust air with hose (~115 dBA), and use of personal protective equipment (ear muffs, glasses, gloves, etc.).

punching of converter tuyeres shortly after sound measurements were completed by the author on August 27, 1974 (Fig. 8). The silencer is fixed to the outside of a tuyere. Operators were pleased with the reduction of noise and improvement in working conditions. The new silencer also eliminates sparks which formerly flew during punching (18). Today's management preferentially purchases machinery which incorporates protection from noise and vibration. The last few years have witnessed the rapid development of automated and remote monitoring equipment (19). The impetus which has initiated changes in the area of monitoring and remote control has been where visual or manual inspection has become inadequate, or for safety reasons. New rapid development and production of very high speed integrated circuits (VHSIC) with higher specifications such as humidity resistance and temperature tolerance improve the speed, reliability and capacity of electronic underground equipment (20). Remote control equipment has not realized the full extent of its potential application due to resistance to change on the part of the mine operators. This is understandable when it is recalled that it has taken sixty years for margarine to displace butter as a table spread because society was not ready for it, and it took only three years from development to the complete acceptance and use of hybrid corn (21). This is an example of habit versus necessity.

INCO Metals Co., Sudbury, uses remote controlled LHD units. When the unit comes to an unsafe area of the stope, the LHD operator uses the cable-remote control (Fig. 9). The operator is completely safe and he is not exposed to noise and vibration during loading. Falconbridge is introducing radio-remote controlled haulage units developed in Sweden. Many mines use remote control in the operation of major ventilation system components. Mechanization of open pit mining using computer control is starting to find application in Canada (22). Problems with weather conditions continue to limit this technology. The

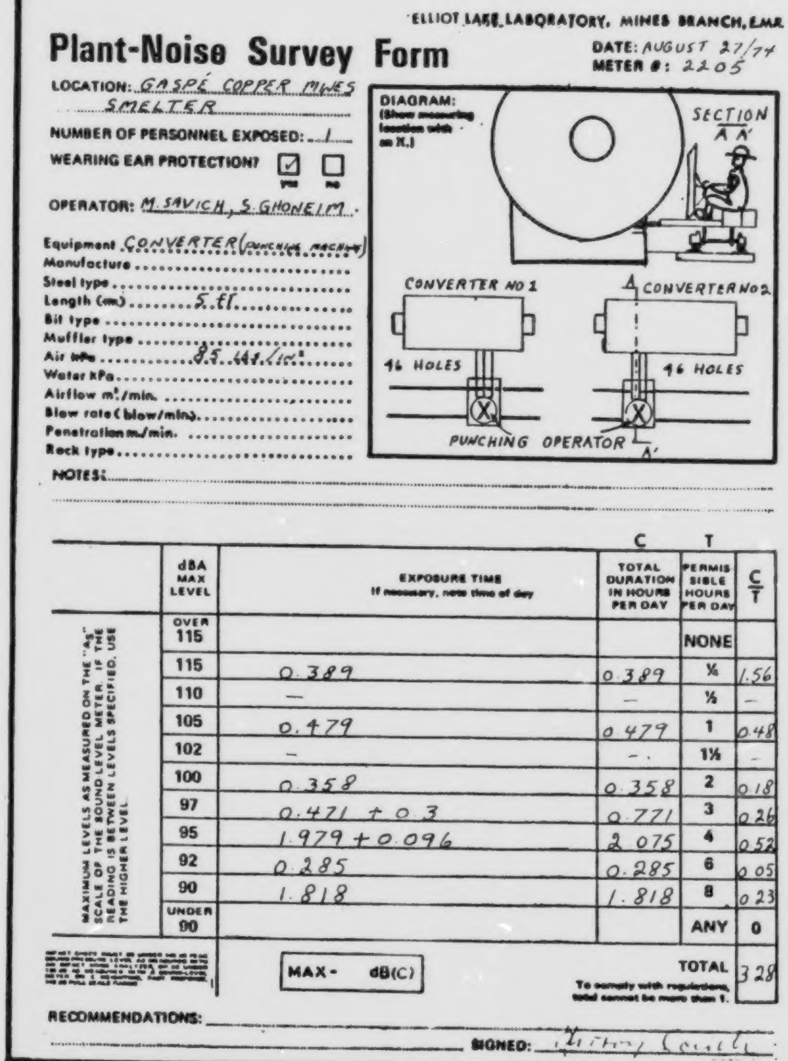


DIAGRAM:
(Show measuring location with an X.)
SECTION
A A'
CONVERTER NO 1
CONVERTER NO 2
A
46 HOLES
46 HOLES
X
X
PUNCHING OPERATOR
A'

ELLIOT LAKE LABORATORY, MINES BRANCH, EMR

Plant-Noise Survey Form

DATE: AUGUST 27/74
METER #: 2205

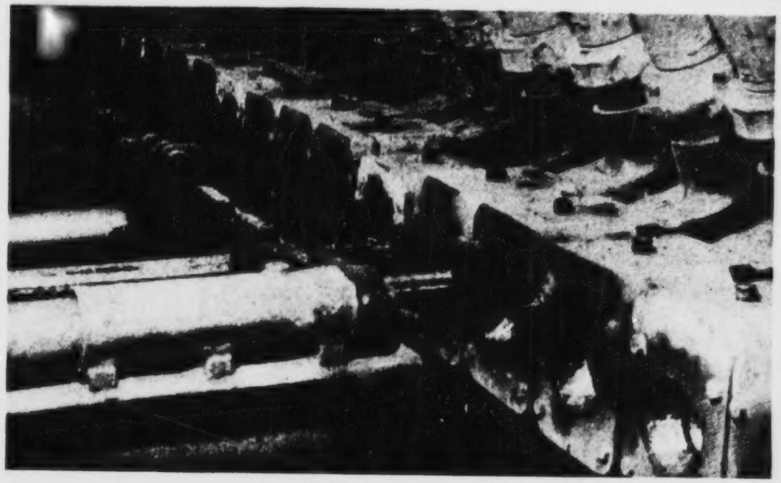
LOCATION: GASPÉ COPPER MINES SMELTER
NUMBER OF PERSONNEL EXPOSED: 1
WEARING EAR PROTECTION? ☑ yes ☐ no
OPERATOR: M. SAVICH, S. GHONEIM.

Equipment CONVERTER (punching machine)
Manufacture
Steel type
Length (m) 5 ft
Bit type
Muffler type
Air kPa 85 lbs/in²
Water kPa
Airflow m³/min.
Blow rate (blow/min)
Penetration m/min.
Rock type
NOTES:

	dBA MAX LEVEL	EXPOSURE TIME If necessary, note time of day	C TOTAL DURATION IN HOURS PER DAY	T PERMISSIBLE HOURS PER DAY	$\frac{C}{T}$
MAXIMUM LEVELS AS MEASURED ON THE "A$_S$" SCALE OF THE SOUND LEVEL METER. IF THE READING IS BETWEEN LEVELS SPECIFIED, USE THE HIGHER LEVEL.	OVER 115			NONE	
	115	0.389	0.389	¼	1.56
	110	—	—	½	—
	105	0.479	0.479	1	0.48
	102	—	—	1½	—
	100	0.358	0.358	2	0.18
	97	0.471 + 0.3	0.771	3	0.26
	95	1.979 + 0.096	2.075	4	0.52
	92	0.285	0.285	6	0.05
	90	1.818	1.818	8	0.23
	UNDER 90			ANY	0
		MAX- dB(C)		TOTAL To comply with regulations, total cannot be more than 1.	3.28

RECOMMENDATIONS:

SIGNED:



The tuyeres and the Gaspé Puncher.

Mr. Coté and his silencer.

Fig. 8 - Noise survey at the Gaspé Copper Mines smelter.

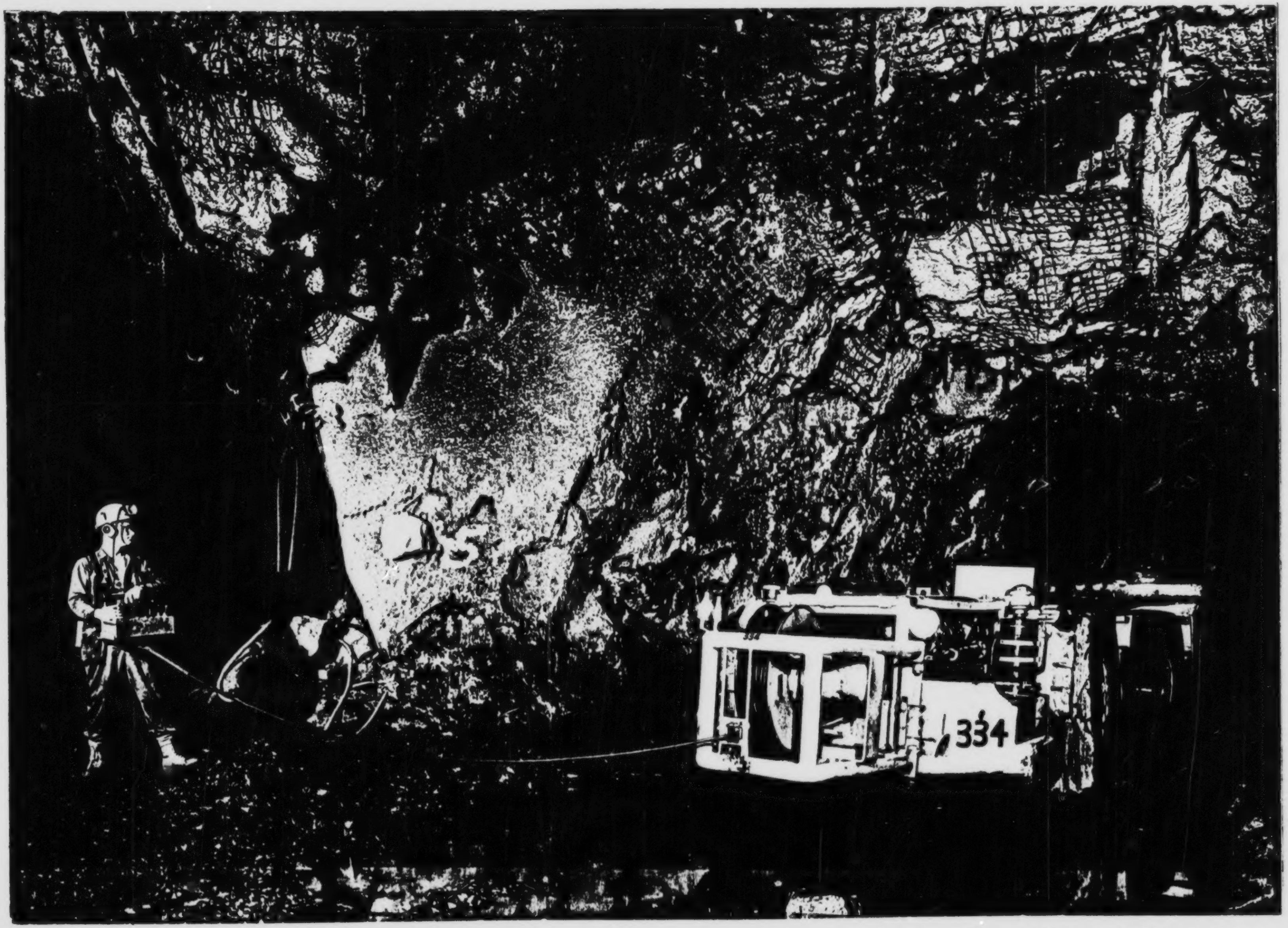


Photo: INCO METALS

Fig. 9 - Remote control device for diesel-powered load-haul-dump unit.

following advantages can be realized with full mechanization using automated control:

- safer mining operation;
- reduction of operator exposure;
- elimination of truck accidents caused by human error.

Canada will move rapidly towards full mechanization as production and productivity must increase to meet economic and environmental pressure. Organization of a robotics industry is underway involving many high technology firms in closely related development work, particularly as computer integrated manufacturing (CIM), flexible manufacturing systems (FMS) and direct-numerical-control (DNC) (23,24,25). The new robotic technology will increase production, reduce operation time (by working 24 hours continuous), use fewer machines, and smaller working areas free from environmental constraints. Noise and vibration, dust, light, and other components of the underground environment will be reconsidered in a new focus. The importance of this change is evident in the words of G. Stenning of Denison Mines (26):

> "The ventilation capacity since 1974 has more than tripled and may be expected to double again during future expansion ...
> The direct capital cost of the new airways and fan installations certainly highlights the major cost items, but a large part of the increasing ventilation costs occur in taking air to the working places."

Future development must be concerned with cost control. With regard to drilling, which is the major source of noise and vibration, all indications point to a return to compressed air. Compressed air is expected to prove less expensive and the initial cost of this equipment is very low. With automated drills noise and vibration controls are unnecessary and maximum drill speeds may be increased to their mechanical limit to increase penetration rates. It is obvious that this offers great advantages.

AUDIOMETRIC TESTING

In Canadian mines audiometric testing commenced in 1965 (27). The first tests were conducted at INCO METALS in Sudbury and later throughout Ontario and the rest of Canada. This may have been expected as INCO METALS employs some 13,000 persons and currently mines 9,000,000 tons annually producing 15 elements.

Presently audiometric testing is mandatory in all Canadian mines. In some provinces testing is the responsibility of the mines while in others it is a governmental responsibility. Testing is done in hospitals or medical centres or at the mine site in audiometric rooms or in mobile audiometric testing units (Fig. 10). Generally, tests meet the Canadian Standard CSA Z 107.4-1975 requirements (28). Pre-employment tests are obligatory. Complete analyses of test results are classified in two categories (Fig. 11):

1. A significant adverse threshold change; and
2. No threshold change.

A significant change in the threshold indicates hearing loss greater than 15 dB from the previous audiogram in one frequency, or a definite pattern of a lesser degree over a wider range. This occurs for a small group of employees in mines. A second group is usually a large group of employees. This group show no threshold change from one year to another, and has three sub-groups and each requires a different approach. Finally, some mines or provinces have a different schematic layout of the audiometric test program, however, they are substantially the same, as may be noted in Fig. 11.

Complete analysis of an employee's hearing conservation program must be

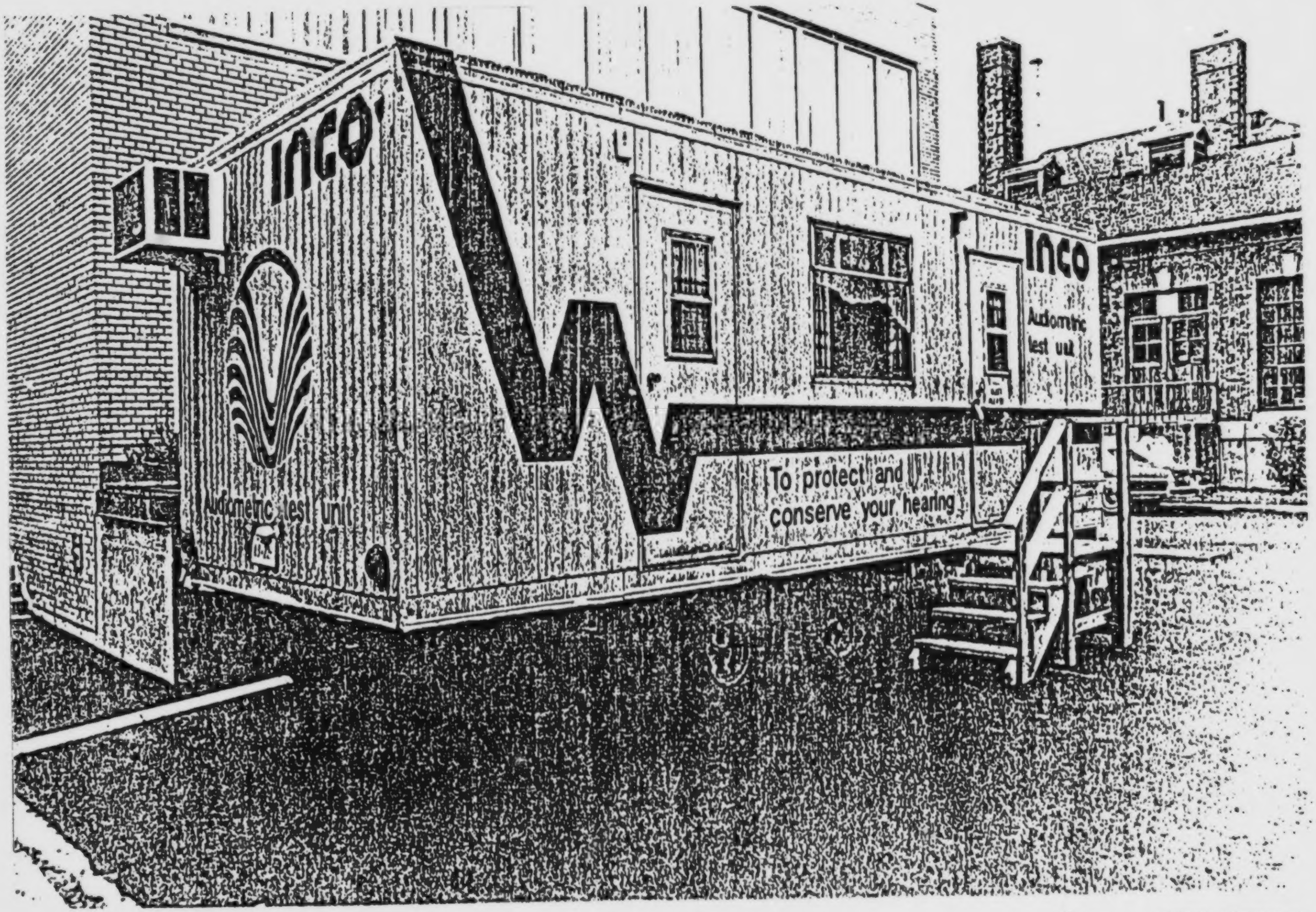

INCO
Audiometric test unit
To protect and
conserve your hearing
INCO
Audiometric
test unit

Photo: INCO METALS

Fig. 10 - Mobile audiometric testing unit at INCO (27).

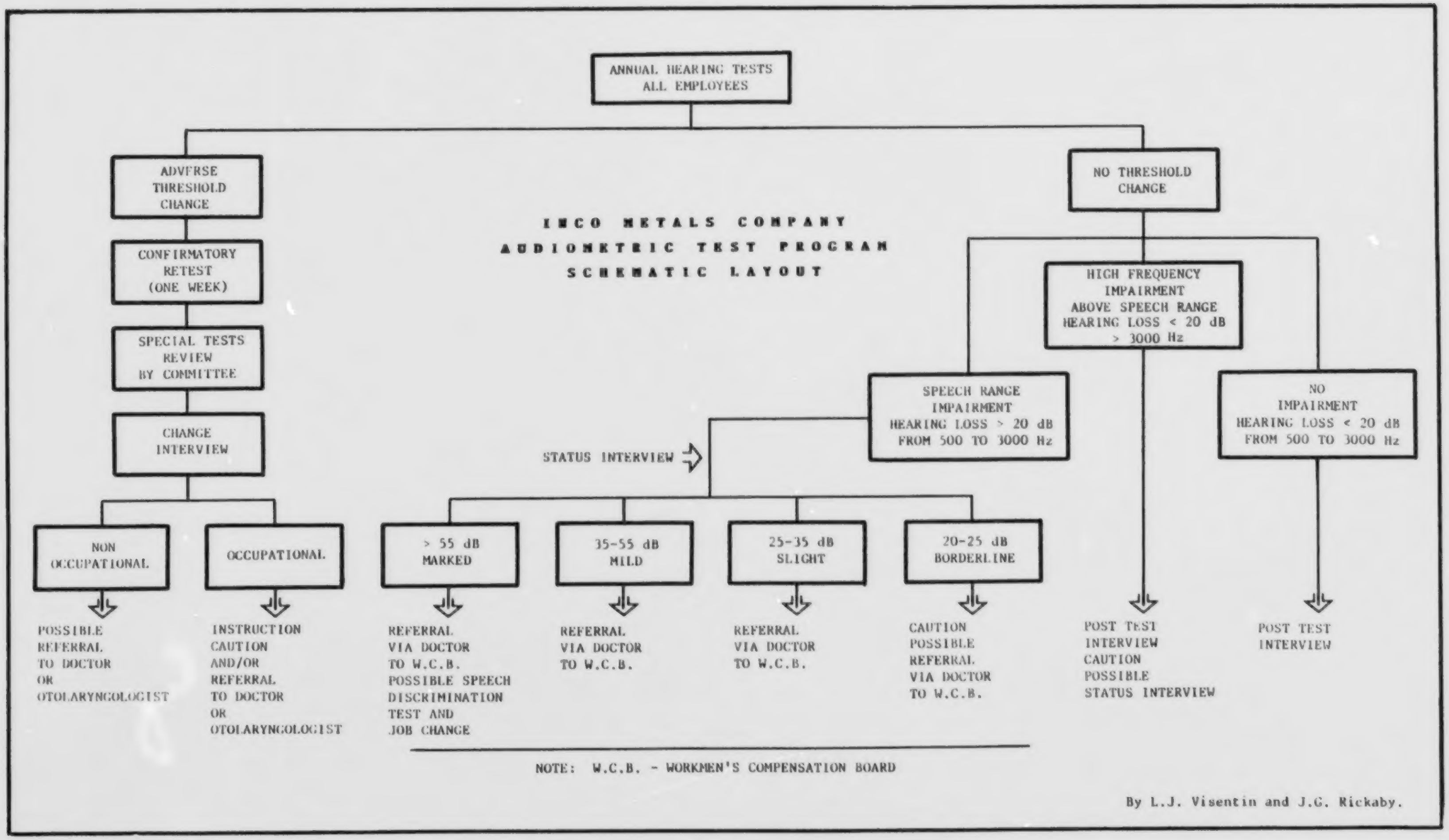

ANNUAL HEARING TESTS ALL EMPLOYEES
ADVFRSE THRESHOLD CHANGE
CONFIRMATORY RETEST (ONE WEEK)
SPECIAL TESTS REVIEW BY COMMITTEE
CHANGE INTERVIEW
NON OCCUPATIONAL
POSSIBLE REFERRAL TO DOCTOR OR OTOLARYNGOLOGIST
OCCUPATIONAL
INSTRUCTION CAUTION AND/OR REFERRAL TO DOCTOR OR OTOLARYNGOLOGIST
INCO METALS COMPANY
AUDIOMETRIC TEST PROGRAM
SCHEMATIC LAYOUT
NO THRESHOLD CHANGE
SPEECH RANGE IMPAIRMENT HEARING LOSS > 20 dB FROM 500 TO 3000 Hz
HIGH FREQUENCY IMPAIRMENT ABOVE SPEECH RANGE HEARING LOSS < 20 dB > 3000 Hz
NO IMPAIRMENT HEARING LOSS < 20 dB FROM 500 TO 3000 Hz
STATUS INTERVIEW
> 55 dB MARKED
REFERRAL VIA DOCTOR TO W.C.B. POSSIBLE SPEECH DISCRIMINATION TEST AND JOB CHANGE
35-55 dB MILD
REFERRAL VIA DOCTOR TO W.C.B.
25-35 dB SLIGHT
REFERRAL VIA DOCTOR TO W.C.B.
20-25 dB BORDERLINE
CAUTION POSSIBLE REFERRAL VIA DOCTOR TO W.C.B.
POST TEST INTERVIEW CAUTION POSSIBLE STATUS INTERVIEW
POST TEST INTERVIEW
NOTE: W.C.B. - WORKMEN'S COMPENSATION BOARD
By L.J. Visentin and J.G. Rickaby.

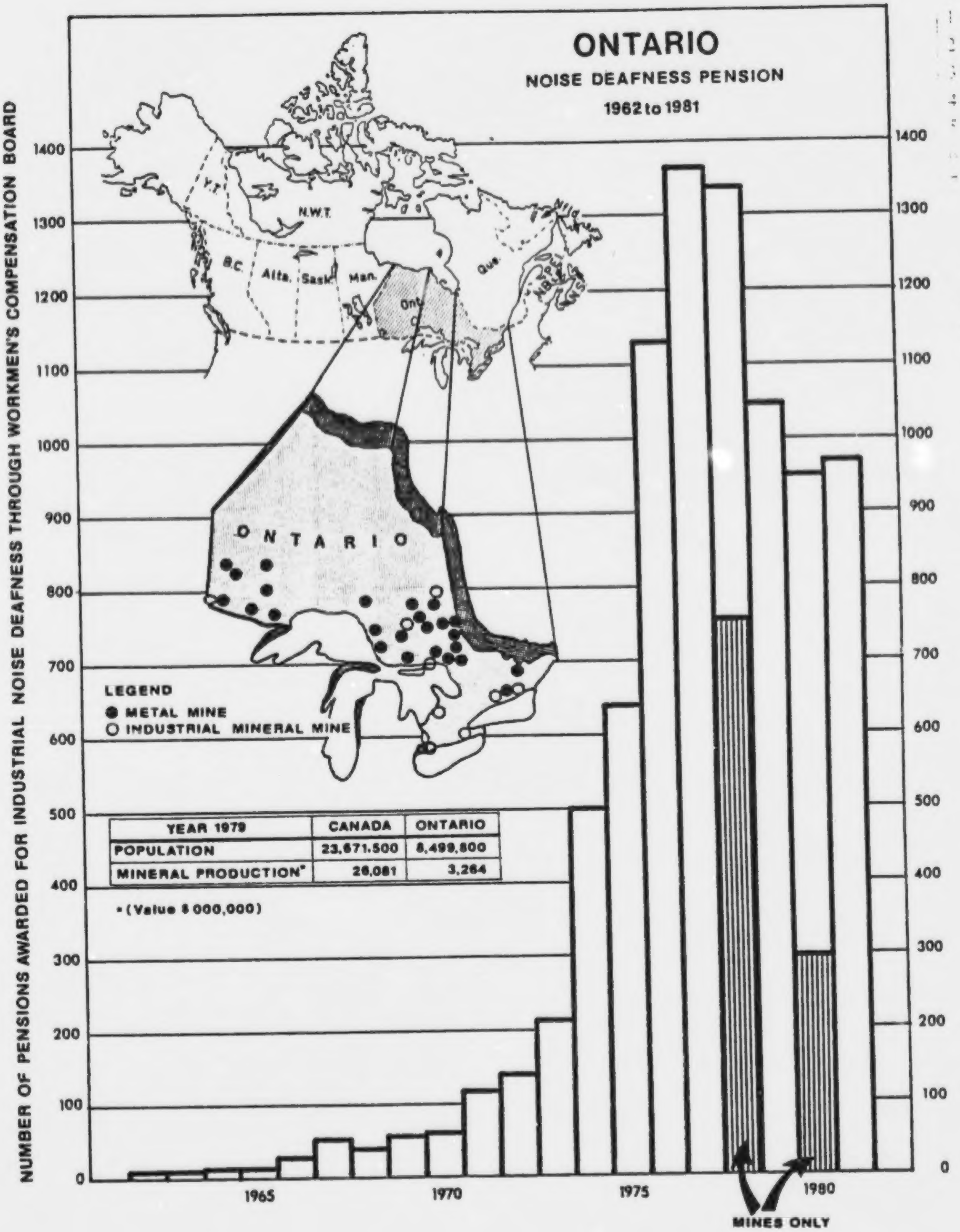
Fig. 11 - Schematic layout of the audiometric test program at INCO (27).

reported to the manager of a plant. The audiometric test co-ordinator, on the basis of complete test results for each employee, will discuss with the manager all aspects of importance: the effectiveness of the conservation program and any constructive recommendations, based on the findings.

ANALYSIS OF INDUSTRIAL NOISE DEAFNESS

Industrial noise deafness in Canadian industry reached a peak level in 1977-78 (29). The adopted measures for hearing conservation have resulted in a decline from that period to the present time. Two provinces were selected for a detailed study, Ontario, which has adopted the OSHA criteria, and British Columbia which applied the ISO standard. Ontario has the largest population, greatest industrialization and largest mining industry. In British Columbia the major industry is forestry followed by mining.

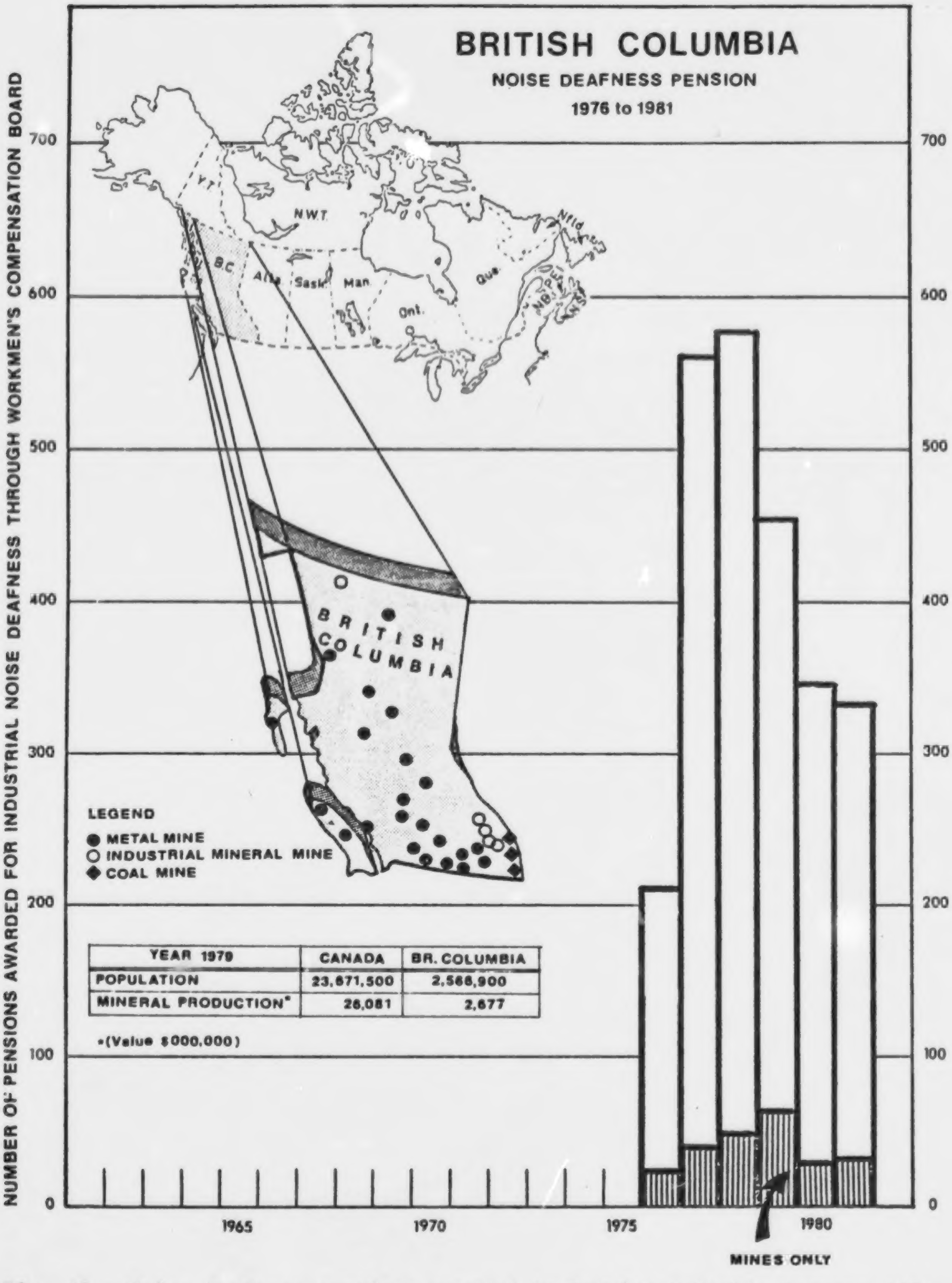
In Ontario the number of pensions awarded for industrial noise deafness in 1978 was far greater in the mining industry than for the remaining industries combined, while in 1980 the figures are reversed (Fig. 12). It would be a mistake to interpret this result as solely the product of hearing protection measures. During the period 1978-1980 the mining industry experienced a massive influx of new labour. Future years will show the effectiveness of the hearing protection measures adopted. Organized protection programs for noise and vibration began later (1976) in British Columbia (Fig. 13). Analysis has shown that the number of pensions awarded for industrial noise deafness is far less in the mining industry than in the remaining industries (Table 1 and Fig. 13). The results show that the controls are enforced and that the protection provided is good and effective. The Government of British Columbia requires that mines purchase equipment complete with noise and vibration protection. Computer modelling techniques in an open pit mine have been conducted in British Columbia to determine the sensitivity of the mine production to factors such as road condition and lengths, different truck sizes and speeds,



YEAR 1979	CANADA	ONTARIO
POPULATION	23,671.500	8,499,800
MINERAL PRODUCTION*	26,081	3,264

*(Value $000,000)

Fig. 12 - Noise deafness pensions awarded in Ontario between 1961 and 1981. Note: The average award in 1976 was $8,500 (29), and in 1981 was $8,804.



YEAR 1979	CANADA	BR. COLUMBIA
POPULATION	23,671,500	2,566,900
MINERAL PRODUCTION*	26,081	2,677

*(Value $000,000)

Fig. 13 - Noise deafness pensions awarded in British Columbia between 1976 and 1981. Note: The average award in 1973 was $8,212, and in 1981 was $7,874.

Table 1 - Hearing loss claim counts for claims first paid in each of the years.

Industry	Year 1981	1980	1979	1978	1977	1976
Metal and industrial mineral mine	37	33	62	46	32	13
Coal mine	2	1	1	3	7	1

Workers' Compensation Board of B.C.

etc. (30). With greater computer control of open pit mining we may expect new reductions of noise.

In the remaining provinces the indications are positive, particularly in Quebec which experiences the problems described for both Ontario and British Columbia.

CONCLUSION

Mining has always played a large role in the progress of civilization, though this has never been recognized by historians or the general public, the reason being the historian's lack of understanding of the techniques of mining and metallurgy and his aversion to discussing such matters (31). Today it is clear that mining and metallurgy are one of the major driving forces in the advancement of civilization and society. However, this advancement has produced major environmental problems, particularly in the mining industry, including noise and vibration, dust, etc. The Canadian mining industry has taken measures in an effort to protect the environment, create satisfactory working conditions and compensate affected employees. The idea, that companies need not spend thousands of dollars to reduce noise and vibration levels from machinery when for a few hundred dollars each worker could be supplied with ear plugs, has long been abandoned. The miner must see and hear everything, so that he may work undisturbed and escape dangerous conditions. Regulations and standards have helped further advancement, however, hearing protection is still required in all Canadian mines. Current progress in the mining industry has demonstrated the value of the decentralized approach to noise and vibration control.

CANMET has developed automated measurement of the noise exposure index in Canadian mines. This is the new generation of noise dosimeters which are coupled with computers. This system of measurement has two objectives: to protect the hearing of the worker and to increase productivity. Annual audiometric testing is obligatory and often automatic with computerized medical recording systems. Decreasing trends in the number of noise deafness pensions awarded in Canada over the past few years demonstrate the positive steps made in hearing loss protection.

On the shores of the Great Lakes more than 8,000 years ago the first mining efforts were made with a stone in hand (2). In the great industrial revolution the largest automobile industry in the world was built in Detroit, and the first hydroelectric generating station at Niagara Falls, with the Manhattan project in Chicago the doors were opened to atomic energy for industry. In Ontario the world's largest nuclear powered electrical generating plants have been built. Once again on the shores of the Great Lakes the newest technological revolution is advancing with the development of electronic working machines, robots. Further automation in the form of robots will enter the industrial scene of industrial and labour relations. The mining machine industry and research have to support development and create a positive environment for advancement to provide solutions to our most pressing problems: providing Canadian mines and mills with advanced technology to become effective, economical and environmentally acceptable, and more competitive in world markets. Technology should also provide solutions to our pressing social problem, unemployment (9). The implementation of new impulses in re-structuring the Canadian mining industry will be phenomenal in cost.

In a world of rapid population growth economic and social factors will affect the total environment, and conflict between developed and developing countries will presumably remain until the year 2,000 (32). Man does not live by safety alone. Zero risk and absolute safety are indeed costly illusions.

Canada has the dimensions of a continent with great regional differences in climate, demography and natural wealth. Because of this it is necessary to utilize technology to control space and time to preserve national unity. The Canadian role in the historical development of noise and vibration measurement is best illustrated by the name of the basic unit utilized, the bell, named after Alexander G. Bell (1847-1922), Canadian inventor and physicist. This is a part of our heritage and an indication of our future and the future of the world.

ACKNOWLEDGEMENTS

The author wishes to thank all of the mines that have supported the Elliot Lake Laboratory, Mining Research Centre, CANMET, E.M.R., and the many colleagues in the mines and the Elliot Lake Laboratory who have been involved. Thanks are also extended to the Workmen's Conpensation Board of Ontario and Workers' Compensation Board of British Columbia for helpful information.

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VoL. 5 Report 7

Noranda Mines Ltd. : J.C.R. Cyr

Cost effectiveness and technical feasability of options available for sound-proofing diamond drilling equipment : phase III

CANMET contract No. OSQ 81-00160

Rep. No. 1-9045 (1983)

CONTRACT RESEARCH REPORT NO. 54

COST EFFECTIVENESS AND TECHNICAL FEASIBILITY OF OPTIONS AVAILABLE FOR SOUND-PROOFING DIAMOND DRILLING EQUIPMENT - PHASE 3

(DSS Contract 14SQ.23440-1-9045)

MARCH 1983

by

J. C. R. CYR, P. Eng.
CA Engineering Services

On behalf of

NORANDA RESEARCH CENTRE
240 Hymus Boulevard
Pointe Claire, Québec
H9R 1G5

RÉSUMÉ

Le présent rapport traite de la troisième étape d'une série continue d'études sur la suppression du bruit produit par des perforatrices au diamant, réalisées pour le compte de la Canadian Diamond Drilling Association et avec sa collaboration. Ce projet est financé par le Centre canadien de la technologie des minéraux et de l'énergie (CANMET) dans le cadre de son programme permanent d'appui à l'industrie canadienne de foration au diamant dans des secteurs de préoccupation immédiate. En résumé, la première étude a consisté à analyser la situation générale en fonction des niveaux de bruit de tous les types de perforatrices au diamant et a révélé que le bruit produit par presque toutes les perforatrices dépassaient les niveaux de bruit acceptables dans les règlements provinciaux en vigueur à travers le Canada. La deuxième étude consistait à quantifier certaines des principales sources de bruit des perforatrices pneumatiques et diesel et à analyser les équipements, les matériaux et les méthodes actuels de lutte contre le bruit qui pourraient être appliqués aux perforatrices au diamant. La présente étude met l'accent sur les perforatrices alimentées au diesel et utilisées dans les mines à ciel ouvert, reportant l'étude des perforatrices pneumatiques en quatrième étape, et traite de la faisabilité technique et économique de l'application des mesures de lutte contre le bruit proposées aux groupes moteur, aux extrémités frontales et aux poupées des perforatrices les plus utilisées dans les mines à ciel ouvert au Canada.

Les résultats d'étude sur des boitiers accoustiques prototypes pour moteurs, de nouveaux trains d'engrenage pour extrémités frontales et poupées ainsi

que diverses poupées pivotantes sont présentées. Sont également présentées des mises à jour d'enquêtes antérieures auprès de l'industrie concernant les types d'équipements de foration actuellement utilisés au Canada et des dispositifs de lutte contre le bruit fabriqués commercialement par des fabricants de perforatrices au diamant.

Selon les informations recueillies à ce jour, l'atténuation du bruit produit par des perforatrices pour mines à ciel ouvert semble être techniquement et économiquement possible jusqu'au niveau de 90-93 dBA. Des changements importants devront peut-être être apportés à la perforatrice classique si des niveaux d'intensité de bruit inférieurs ne doivent pas être dépassés. Cependant, ces changements ne seront vraisemblablement pas nécessaires étant donné que l'exposition moyenne quotidienne au bruit de l'opérateur de perforatrice est habituellement inférieure aux niveaux de bruit instantanés susmentionnés et qu'elle devrait donc être conforme à la plupart des règlements actuels sur le bruit.

Fondées sur cette étude, des recommandations sont faites pour mettre en oeuvre les mesures de traitement du bruit nécessaires pour atteindre l'objectif ci-dessus. Il est en outre recommandé que les études futures mettent l'accent sur les perforatrices au diamant pneumatiques souterraines.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the active participation and contributions of several individuals in connection with this project. Messrs. P. Nguyen and G. Leroux of Noranda Research Centre both carried out and assisted with most of the field measurements reported herein, analyzed resulting data, and generated interim reports. Dr. L. T. Russell of the Technical University of Nova Scotia originated most of the preliminary design concepts generated as potential alternatives to the existing swivel head arrangement on surface drills, and provided most of the commentary in Section 10.2 herein. Mr. L. B. Geller of CANMET spearheaded the fabrication and testing of a prototype acoustical engine enclosure, provided most of the information contained in Section 7 and Appendix C herein, and also provided some very helpful editorial comments on the draft report.

Special thanks are also offered to Midwest Drilling Co. of Winnipeg for the loan of a BBS-37 drill to CANMET for the purpose of the above study, to Mr. G. Wright and staff of Logan Drilling Limited in Musquodoboit, N. S., for their helpful comments and assistance, to Messrs. C. Smith and M. Smith of Wallace, N. S., for allowing an intrusion into their normal drilling operation for the benefit of science and fellow drillers, to Mr. R. Laporte and staff of St. Lambert Drilling Co. Ltd. and staff of Sprague and Henwood Inc. for their candid discussions of noise suppression work undertaken independently by their companies.

The helpful comments and guidance from the Technical Committee of the Canadian Diamond Drilling Association is both acknowledged and appreciated. The special contributions of Messrs. G. Pipher, C. Watson and D. Holland are particularly noted.

ABSTRACT

This report addresses the third stage in a continuing series of studies on diamond drill noise suppression conducted on behalf of, and in cooperation with, the Canadian Diamond Drilling Association (C.D.D.A.). The project is funded by the Canada Centre for Mineral and Energy Technology (CANMET) as part of their ongoing program to support the Canadian Diamond Drilling Industry in problem areas of immediate concern. In brief, the first study examined the general situation with respect to operating noise levels with all classes of diamond drills, and found that virtually all drills exceeded provincial noise regulations currently in force across Canada. The second study quantified some of the principal noise sources on diesel and pneumatically powered drills, and reviewed available noise control equipment, materials and methods which might be appropriate for use on diamond drills. The present study focuses on diesel-powered surface drills, deferring pneumatics until Stage 4, and addresses the technical and economic feasibility of implementing proposed noise controls on the power packs, front ends and heads of the more commonly used surface drills in Canada.

Results of studies on prototype acoustical engine enclosures, alternate gear sets for front ends and heads, and alternate swivel head arrangements are reported, along with updates on earlier surveys within the industry regarding the types of drilling equipment currently used in Canada, and noise control features now commercially available from diamond drill manufacturers.

Information available to date indicates that noise control on surface drills appears to be technically and economically feasible to the 90 - 93 dBA level. Major changes in conventional drill design may be necessary if lower noise emission levels must be achieved. However, the need for such is unlikely since a drill operator's average daily noise level exposure will usually be lower than the instantaneous noise levels quoted above, and should therefore comply with most existing noise regulations.

On the basis of this study, recommendations are made to implement the noise treatments required to achieve the above target. It is also recommended that the focus of future studies be shifted to underground pneumatic diamond drills.

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1. OBJECTIVES

1.1 To establish the technical feasibility of previously-proposed noise treatments for the power pack, front end and head assembly of diesel-powered surface drills.

1.2 To estimate the probable cost of implementing the above, and subsequently examine the economics of proceeding with retrofit noise controls on existing drills or those associated with the replacement of existing equipment with drills of newer and quieter design if the former costs seem unreasonable.

1.3 To define any need for, and direction of, future work on diamond drill noise suppression.

2. SCOPE

2.1 Data from a previous survey of Canadian diamond drill users were updated by CANMET to confirm the types and makes of diamond drills that are most representative of the ones used in Canada.

2.2 Diamond drill and diesel engine manufacturers in Canada, the United States and overseas were surveyed by Noranda Research Centre (principal contractor to CANMET) to see if there had been any recent innovations in noise control which could be purchased as an option with new drills or adapted to existing drills.

2.3 CANMET built and tested a prototype acoustical engine enclosure on a BBS-37 drill equipped with a GM 353 diesel as a means of demonstrating the technical feasibility of silencing drill power packs.

2.4 Noise sources on a Longyear 38 drill were measured under field conditions and rank-ordered by Noranda Research as a check on similar data collected previously on an older model BBS-15.

2.5 Studies of gear sets which might be suitable as quiet-operating options to existing gears in drill front ends and heads, were initiated by Dr. L. T. Russell of the Technical University of Nova Scotia, working in close collaboration with Noranda Research. Alternate swivel head arrangements which would allow the bevel gears in the drill head to always remain in contact were explored, and subsequently discussed with Canadian drill users and manufacturers.

2.6 Noise control options that have been demonstrated on diamond drills to date were reviewed along with attendant costs by Noranda Research in order to identify the most cost-effective manner in which drill owners wanting to implement noise controls could proceed at this time.

3. OBSERVATIONS

3.1 Approximately 74% of the diamond drills used by the Canadian diamond drilling industry are diesel or gas-powered surface drills, and most of these are diesel-powered (69%). Pneumatically-powered underground drills represent most of the balance (24%), with the remainder (2%) being electrically driven underground units.

The most commonly used makes of diesel-powered surface drills are the Dresser-Boyles Model BBS-37 and Longyear Model 38, which are typically equipped with engines in the 60 to 80 HP range and feature mechanical rotation of the drill bit, hydraulic thrust, and a swivel head which hinges at the bevel gears.

3.2 An international survey of diamond drill manufacturers indicated that only one (Sprague & Henwood in the U.S.) actually provides a noise control package for the class of drills described above.

3.3 Most of the major diesel engine manufacturers appear to have some level of noise control activity underway, but only one German manufacturer (Hatz Diesel) is able to claim a noise level of 90 dBA for engines in the 30 to 80 HP range while operating in a normal drill shack environment.

3.4 The technical feasibility of acoustical engine enclosures has been thoroughly demonstrated by CANMET, by at least one engine manufacturer, by at least one drill manufacturer, and by at least one drill user. The latter has also demonstrated cost feasibility under normal market conditions.

3.5 Noise measurements on a recently-purchased Longyear Model 38 drill confirmed the number and importance of noise sources measured previously on an older Model BBS-15 drill. Hence the need for noise controls on each of the power pack, front end and head in order to achieve compliance with noise regulations was also confirmed.

3.6 Preliminary engineering studies have shown that it may be possible to substitute helical gears for existing spur gears in drill front ends, and spiral or hypoid bevel gears for existing straight cut bevel gears in drill heads on a retrofit basis. The latter change would eliminate the popular swivel head feature, however.

At least one U.S. drill manufacturer (Sprague & Henwood Inc.) already offers both options as part of a noise control package. There was no apparent need for a major drill redesign effort in order to implement these changes.

3.7 Preliminary engineering studies have shown that it may be possible to redesign the existing head assembly on drills in a manner which will allow the head to remain permanently closed (and, therefore the use of spiral gears), yet still allow the head to swing away by altering the mechanical linkage to the remainder of the drive train.

Initial discussions with drill manufacturers have indicated these modifications could only be accomplished at considerable cost. Subsequent discussions with drill users have raised questions of whether the swivel head feature is expendable when trying to achieve compliance with provincial noise regulations at a reasonable cost.

3.8 Noise controls that have been demonstrated on various diamond drills to date indicate that an overall noise level of 90 - 93 dBA is probably achievable on the class of drills of interest using retrofit noise control treatments. Elimination of the swivel head is necessary in this case, however. Drill users who are able to install the required treatments themselves should be able to do so at an approximate cost of $8,000, which includes material and labour. Actual costs and difficulties which may be encountered in implementing these treatments on BBS-37 or Longyear 38 drills remain to be determined.

4. CONCLUSIONS

4.1 Since the majority of diamond drills used in Canada are diesel-powered surface drills, efforts to alleviate noise problems associated with this class of drills are well conceived.

4.2 There is ample room in the market for drill manufacturers wanting to take a lead position in providing noise control options for their equipment.

4.3 Diesel engine noise emissions will gradually decrease over the long term. At this time, however, only the Hatz diesels can comply with provincial noise regulations; they will probably retain that distinction over the near term.

4.4 Acoustical engine enclosures are now a proven noise control method for diamond drills, and any provincial authority could reasonably request that a user install such a device as part of a noise compliance plan.

4.5 Recent noise data confirm the need to treat engine, front end and head noise in order to achieve compliance with provincial regulations.

4.6 It should be possible to install quieter-operating gear sets in existing drills without the need for major design changes in existing gear housings.

4.7 The need to retain the swivel head feature on "quiet" drills should be seriously re-examined by drill users, since the implications of doing so are significant from a cost point of view.

4.8 Under routine drilling conditions, rigs emitting nominal noise levels of 90 - 93 dBA should still be able to comply with provincial noise regulations because the average daily noise exposure of an operator is typically lower than the noise level emitted by the equipment due to the normal rest periods, intermittent shutdowns, etc. encountered during a regular working day. Exceptions can occur when the normal working shift is extended, or during particularly intensive production periods.

5. RECOMMENDATIONS

5.1 Some unfinished work on engine enclosures and gears should be carried out (as described below) in order to properly complete the studies on the surface class of drills. However, the thrust of continuing studies on diamond drills should now be shifted to pneumatic drills, where a systematic examination of the relevant noise sources and appropriate noise treatments should be undertaken.

5.2 Diamond drill manufacturers operating in Canada should consider making noise control options available to future buyers so that the need for retrofit noise controls can be eliminated. Meanwhile, Canadian drill users in the market for a new drill have the option of buying drills equipped with a noise control package from abroad.

5.3 By late 1983, "quiet" diesel engines over the full range of 30 to 80 HP should be available from at least one supplier. Drill manufacturers should offer these engines as an option on new drills. Users having to replace an engine should consider purchasing a "silenced" engine at the outset and thereby avoid retrofit costs and problems at a later date.

5.4 Drill users facing the prospect of having to silence existing engines should consider fabricating their own enclosures using the guidelines described later in this report and some supervisory acoustical engineering assistance to ensure that adaptations of the enclosure are in fact installed properly.

A joint demonstration project between an interested user and the Federal Government project-contractor might be the best way of identifying potential problem areas inherent in this approach, and ways of dealing with them for the benefit of subsequent users.

5.5 The possibility of using helical and spiral gears to treat existing gear noise problems should be examined further.

5.6 An interested drill user should consider carrying out a joint study with the Federal Government project-contractors to determine if simple gear substitutions can be made in the front end and head, and to measure the effects of making these changes.

5.7 Consideration should be given to abandoning the swivel head feature in favour of some other appropriate solution (such as retractable drills).

5.8 Drill users should start to phase in retrofit noise controls on existing equipment as soon as possible and as quickly as resources permit. New equipment should be purchased with noise controls already installed in order to avoid problems and retrofit costs at a later date.

6. INTRODUCTION

Earlier studies on diesel-powered surface drills had shown that several major drill components, namely the power pack, front end, and head (also the water pump when powered by a separate diesel engine), were collectively responsible for overall noise levels of 100-107 dBA observed on rigs operating under normal drilling conditions. Moreover, it was shown that all of the major noise components would have to be treated if compliance with existing provincial noise regulations is to be achieved. Suggestions for treating each individual noise source were made, but remained to be technically proven(1,2).

The thrust of this study was directed at demonstrating the technical feasibility of acoustical engine enclosures, identifying, in cooperation with Canadian drill manufacturers, suitable noise-reducing design changes for both the front ends and heads, and examining the cost/benefit aspects of retrofitting existing drills with the above modifications. Although the demonstration work did not proceed as far as originally planned, contact with a U.S. diamond drill manufacturer who had already implemented most of the modifications being considered enabled most of the study's goals to be achieved. Various activities carried out over the course of 1982 in connection with the above goals are summarized herein, together with suggested noise control actions.

7. UPDATE OF DRILL USE SURVEY

As a check on the type of drilling rig/power pack combinations which best represent the ones currently used in Canada, CANMET re-examined and updated the results of an equipment survey undertaken at the outset of the diamond drill noise suppression studies(1). A total of 21 firms had responded to the survey, representing the Atlantic Provinces (3), Québec (7), Ontario (5), Manitoba (1), British Columbia (4), and the Yukon (1). The reported numbers and makes of drills in use in 1980 are summarized in Table 1(3). It is evident that Boyles and Longyear drills are currently the most commonly used models.

TABLE 1 - NUMBERS & MAKES OF SURFACE DRILLS IN USE IN CANADA DURING 1980

	MAKES	NO.	% OF TOTAL
1.	Boyles	243	49
2.	Longyear	163	33
3.	J. K. Smit	16	3
4.	Wesdrill	3	<1
5.	Inspiration	20	4
6.	Acker	9	2
7.	Heath and Sherwood	15	3
8.	Chicago Pneumatic	3	<1
9.	Atlas Copco	4	<1
10.	St. Lambert Drilling Ltd.	8	2
11.	Morissette	1	<1
12.	Joy	1	<1
13.	Homemade	6	<1
		492	100

Table 2 (3) summarizes the models within the Boyles and Longyear makes in use at the time of survey.

TABLE 2 - DRILL MODELS MOST COMMONLY USED IN CANADA IN 1980

BOYLES MODELS			LONGYEAR MODELS		
Model No.	No. of Units	% of Total	Model No.	No. of Units	% of Total
1 or 15	36	15	24	4	2
17 or 25	103	42	34	1	1
35 or 37	72	30	38	103	63
45 or 56	30	12	44	48	30
3 or 70	2	1	HC-150	5	3
			Hydra Core 28	2	1
	243	100		163	100

Inspection of Table 2 indicates that the Boyles Models 25 and 37 and Longyear Models 38 and 44 drills are most representative of the class of drills currently used for surface drilling in Canada. Accordingly, noise control studies were focused on this class of drills as recommended by the Technical Committee of the Canadian Diamond Drilling Association.

These drills can be generally characterized as having a mechanical gear train to provide drill rotation (including straight cut bevel gears mounted inside a swivel head), and dual hydraulic cylinders to provide drill feed (i.e. bit thrust) Most drills (95.5%) are powered by diesel engines (versus 2.5% gasoline and 2% electric), and of these, 43% were built by GM, 28% by Ford, 16% by Deutz, 8% by Hatz, and the remainder by Perkins, Caterpillar and others.

8. INTERNATIONAL SURVEY OF DIAMOND DRILL MANUFACTURERS

To insure an awareness of noise suppression activities on an international scale, a survey of drill manufacturers in Canada, the United States and Europe was carried out. Manufacturers, selected from the 1981 Manufacturers' Directory of World Mining Journal, were asked to comment on noise controls already implemented or planned on their diesel power pack, the power train, and/or head. Noise level measurements, equipment pictures, sketches, etc. were also requested where available. A sample letter and a table summarizing who was contacted as well as the essence of the replies obtained is included in Appendix A.

In summary, 13 out of 24 companies contacted eventually responded. Of these, six claim to offer noise-reducing options on their machines. Three manufacturers from this category are located in the United States, one in Canada, one in Sweden, and one in England. The above distribution approximately reflects where noise regulations are most vigorously enforced. It is worthy of note that another British firm is currently examining the prospect of supplying a sound-proofed power pack with their drills, and that the British Drilling Association will include noise as one of several factors to be included in a proposed "Drill Rig Rating". In fact, the author's survey letter was instrumental in reminding the Association of an omission in their recommended specifications; they expressed interest in the work going on in Canada(4-10). Perhaps the above findings are an indication that Canada could establish a lead position in this field.

Regarding the types of noise controls implemented to date, one of the American companies, Sprague & Henwood Inc., appears to have been the most progressive manufacturer, offering drills with modifications to their standard power pack, front end and head. Details are described later in Sections 9.3 and 10.3, but in brief involve soundproofing of the power pack, use of "quiet-operating" gears in the front end, and spiral bevel gears in the head - the same basic design changes which were being sought on

Canadian drills. Overall noise levels in the operator's position of 94.5 dBA were reported with this configuration (and confirmed by personal measurements). A further noise reduction to 90 dBA was reported when acoustical panels were extended beyond the engine enclosure up to and including the front end. However, the latter modifications were not found to be acceptable in practice(11).

Two of the remaining five manufacturers claiming the availability of noise control options offer sound-proofed power packs, and the last three claim reduced noise levels on their drills through the use of helical and spiral cut or unspecified gears at various points in the power trains. The latter claims remain to be substantiated by actual noise level measurements.

An observation which emerges from this survey is that a surface type diamond drill which emits 90 dBA or less (in the operator's position) does not yet appear to be commercially available.

9. POWER PACK CONSIDERATIONS

A three-pronged approach was used in studying possible methods of reducing power pack noise levels. The first consisted of a brief survey of the major diesel engine suppliers to see if any major new developments could be expected in the near future. The second took the form of a demonstration project by CANMET which was intended to show the magnitude of engine noise reduction possible by use of a properly constructed acoustical engine enclosure. The third was to monitor work already underway by the previously-mentioned American firm, Sprague & Henwood Inc., and a Canadian firm, St. Lambert Drilling Ltd. of Valleyfield, (Québec) who was introducing radically new design concepts on a hydraulic drill and drill shack.

The outcome of each study is reported in detail below.

9.1 Survey of Diesel Engine Manufacturers

A brief check of the literature indicates that research on the noise characteristics of internal combustion (IC) engines is being actively pursued in the United States and overseas. In one issue of one journal alone, eight references were found to textbooks and recent papers concerning noise control methods for IC engines including the effects of fuel on diesel engine noise, relationships between cylinder pressure or piston slap and diesel engine noise, the effects of engine block structural design on noise radiation, etc.(12). Unfortunately, none of the work monitored to date appears to suggest that placement on the market of a diesel engine which will operate at noise levels of 90 dBA or less without the aid of acoustical panels is imminent. Nonetheless, great strides are being taken by some manufacturers to reduce noise emissions from their engines in comparison to older models. These efforts are worth noting, especially in the context of new equipment purchases or engine replacements, and engine manufacturers responsible for spearheading this work should be encouraged to continue.

The four principal manufacturers of diesel engines for diamond drills (i.e. GM, Ford, Deutz and Hatz) were contacted to see if any prospect of a "quiet" engine was in the offing. A sample letter to the manufacturers and the replies received are included in Appendix B.

In brief, GM, Ford and Hatz responded. GM included data for their 3, 4 and 6 cylinder 53T series engines showing noise levels of 93, 97 and 96 dBA, respectively, as measured at 1m and 2500 rpm. Ford (England) indicated that a new series of diesel engines (i.e. their 2720 Range) has recently been introduced to replace the older 2710 series, with"significantly reduced noise emissions". Although no specific noise data were reported, it was claimed that a four cylinder model in the new series (i.e. 2722) would emit noise in the low 90 dBA range when measured at three meters. Hatz have added the L40 series of engines to their previous L30 "Silent Power System" to provide power packs ranging from 20 to 80 HP. The L40 engines are claimed to generate approximately the same noise levels as the L30 engines. One of these (a 3L30) was measured by Noranda Research Centre at 90 dBA in the drill operator's position while driving a BBS-15 on site at the Northern College of Applied Arts and Technology(2). Readers not familiar with the Hatz line of engines should realize that the engines come equipped with a very compact acoustical engine enclosure (see Appendix B).

As previously mentioned, the above results are very encouraging; however, the continuing need for acoustical engine enclosures is readily apparent.

Two other interesting developments with respect to diesel engine noise are: (i) the recent announcement by Perkins Engines of Peterborough, England, of a turbocharged four cylinder engine (Model T4236, up to 76 KW) which, among other features, also claims to operate at reduced noise levels(13), and (ii) a practice adopted by drill manufacturers Sprague & Henwood Inc. of modifying a standard semi-enclosed engine by John Deere to produce a functional acoustical engine enclosure. The latter is described in more detail in Section 9.3.

9.2 Prototype Engine Enclosure by CANMET

Quite apart from the question of whether 'quiet' engines have become available for new drills is the problem of having to retrofit engines with noise controls on existing drills. Although the use of acoustical engine enclosures has become commonplace on certain types of equipment like air compressors, several open questions remained as to whether these enclosures could be adapted to diamond drill rigs:

(i) without major modification to existing support structures (e.g. skids, couplings);

(ii) without unacceptably hampering engine access for routine inspection and servicing;

(iii) without adding excessively to existing rig weight (an important factor where rigs have to be flown into the drill site via helicopter);

(iv) without incurring prohibitive costs.

CANMET undertook to build and test a prototype acoustical engine enclosure as a means of shedding light on some of these questions.

Thanks to Midwest Drilling Co. of Winnipeg, CANMET obtained a BBS-37 drill (powered by GM 353 diesel) on loan for the purpose of this demonstration project. It is evident from Section 7 that this drill is fully representative of the class of surface drills most commonly used in Canada. The drill was shipped to Ottawa for fitting of a noise enclosure around its engine in the CANMET shops, and for acoustical performance testing at the CANMET laboratories.

The appearance of the drill before and after fitting of the engine enclosure is shown in Figures 1A and 1B. A general arrangement drawing of the enclosure itself is shown in Figure 2. Salient features worth noting include the labyrinth cooling air and combustion air intakes, warm air exhausts, the engine exhaust muffler, the close-fitting drive shaft exit hole from the enclosure, and the vibration isolation pads inserted between the original skid and diesel engine. The acoustical enclosure panels are a sandwich construction consisting of a 16 ga. steel exterior, a 1 in. fibreglass middle and an expanded metal interior which both protects the fibreglass and holds it in place.

As shown, the enclosure was capable of reducing noise levels in the operator's position from approximately 100* to 80 dBA when the engine was operated alone with the throttle wide open(3,14). The 20 dB reduction obtained compares very favourably with the 15-20 dB design goal selected earlier in the program. Additional tests under simulated load conditions achieved by coupling the engine

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* corrected for reverberation effects

Fig. 1 - BBS-37 DRILL WITH GM353 DIESEL

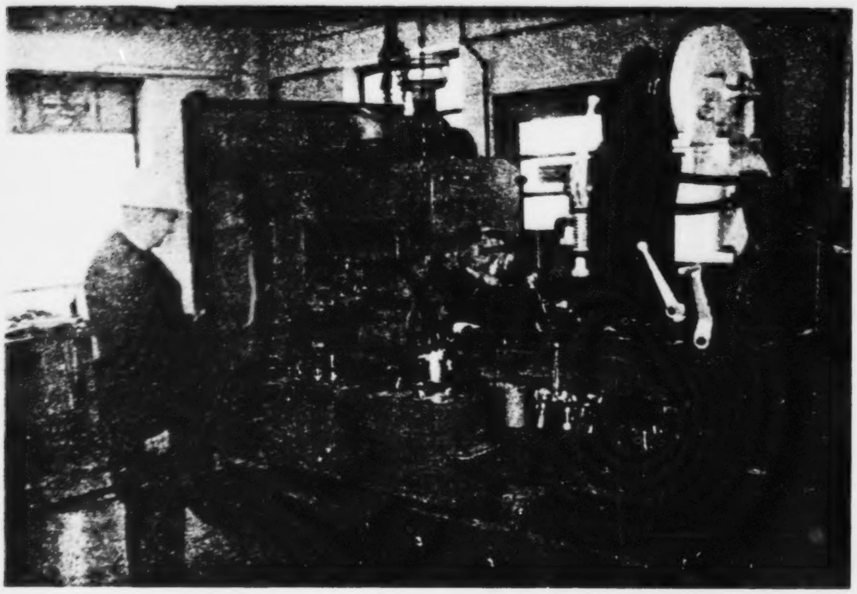


Fig. 1A - Drill In Canmet Shop During
Construction of Engine Enclosure

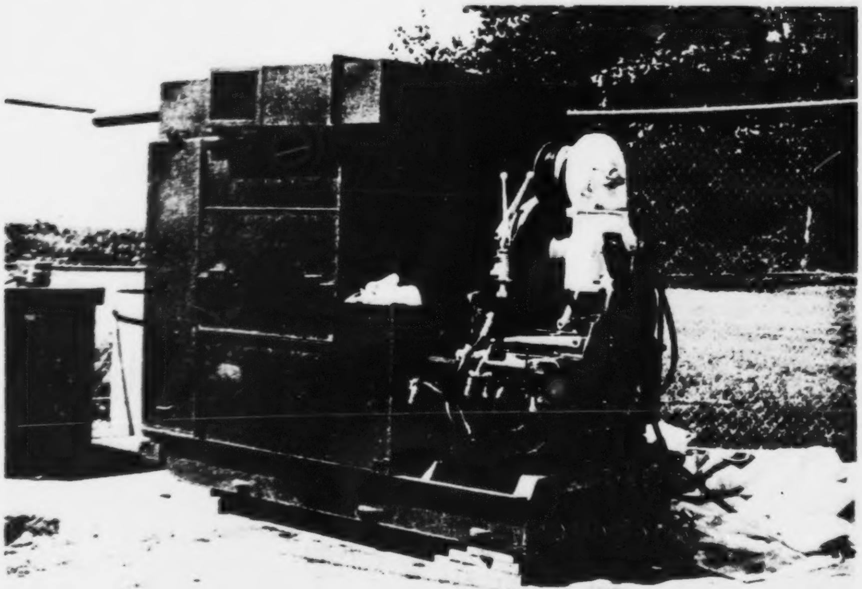
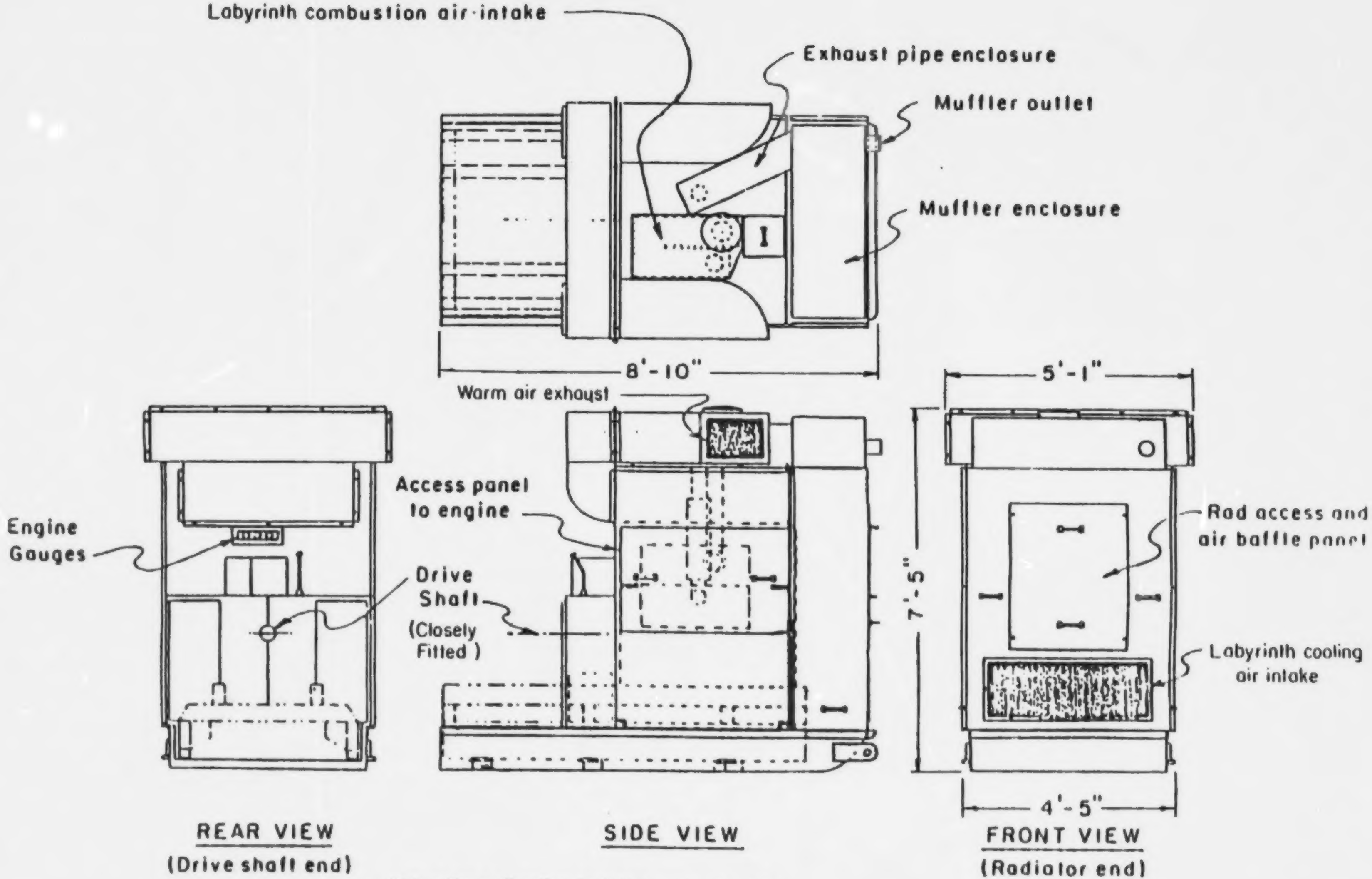


Fig. 1B - Drill with Engine Enclosure
Installed


Labyrinth combustion air-intake
Exhaust pipe enclosure
Muffler outlet
Muffler enclosure
8'-10"
Warm air exhaust
5'-1"
Access panel to engine
Engine Gauges
Drive Shaft (Closely Fitted)
Rad access and air baffle panel
7'-5"
Labyrinth cooling air intake
4'-5"
REAR VIEW
(Drive shaft end)
SIDE VIEW
FRONT VIEW
(Radiator end)

Note: Four vibration isolators were placed between the engine and original skid located inside the stone boat.

Fig. 2 - General Arrangement of Diamond Drill Diesel Engine Sound Enclosure

directly to a dynamometer showed that engine noise levels increase significantly with rpm (typically upwards of 10 dB between idle and full rpm), yet are virtually independent of load. This result is consistent with findings of other researchers(12).

A few difficulties were encountered during the fabrication and testing phases which are worth noting. Because the drill was on loan, all modifications had to be implemented in such a way as to cause minimal disturbance to the original drill configuration. Hence, use of the "stone boat" construction under the original skids and the large bulky panels around the perimeter of all engine surfaces. This resulted in a much heavier and more voluminous construction than was desirable, complicated fitting and sealing around the drive shaft, and ultimately resulted in a diesel fuel overheating problem since the fuel tank remained inside the acoustical enclosure. Normally, an engine enclosure would be much closer fitting and lighter (e.g. Hatz diesel cowlings), would therefore avoid most of the above problems, and would be much easier to fabricate. Hence, although the prototype enclosure amply demonstrated what was technically achievable in terms of engine noise reduction, the enclosure configuration employed (including access panels, etc.), and material and labour costs associated with its construction are somewhat unrepresentative (costs and weight on the high side). A preliminary design which is thought to be more suitable for field use is discussed later in Section 11.

Appendix C contains additional details regarding the prototype enclosure construction and pictures illustrating various stages of construction.

9.3 Engine Enclosure Options From Sprague & Henwood Inc.

The Sprague & Henwood Inc. equivalent of a BBS-37 or Longyear 38 is a Model 142C. It comes equipped with a four-cylinder, water-cooled John Deere diesel engine with comparable horsepower and rpm to the GM 353 (i.e. 63 versus 64 HP at 2200 rpm), and also features mechanical rotation and hydraulic thrust.

Two approaches to engine noise control have been used by Sprague & Henwood Inc. to date which are identical in principle, but quite different in practice. The first is illustrated by Figures 3 and 4, and represents their "partially enclosed" unit. Focusing on the engine portion of the rig only for the moment, Figure 3 shows the standard John Deere engine enclosure, to which is added a 1 in. lining of soundfoam on the two interior surfaces of the side and end visible in Figure 3. Immediately on top of the engine enclosure are the engine exhaust muffler (vertical cylinder) and combustion air intake silencer (horizontal cylinder just behind exhaust muffler). Immediately beneath the engine enclosure are two panels mounted on the drill skids (one is only partially visible in Figure 3, more obvious in Figure 4). These panels act as noise barriers and deflect noise from the bottom of the engine enclosure (which is open) away from the operator. The panels are fabricated out

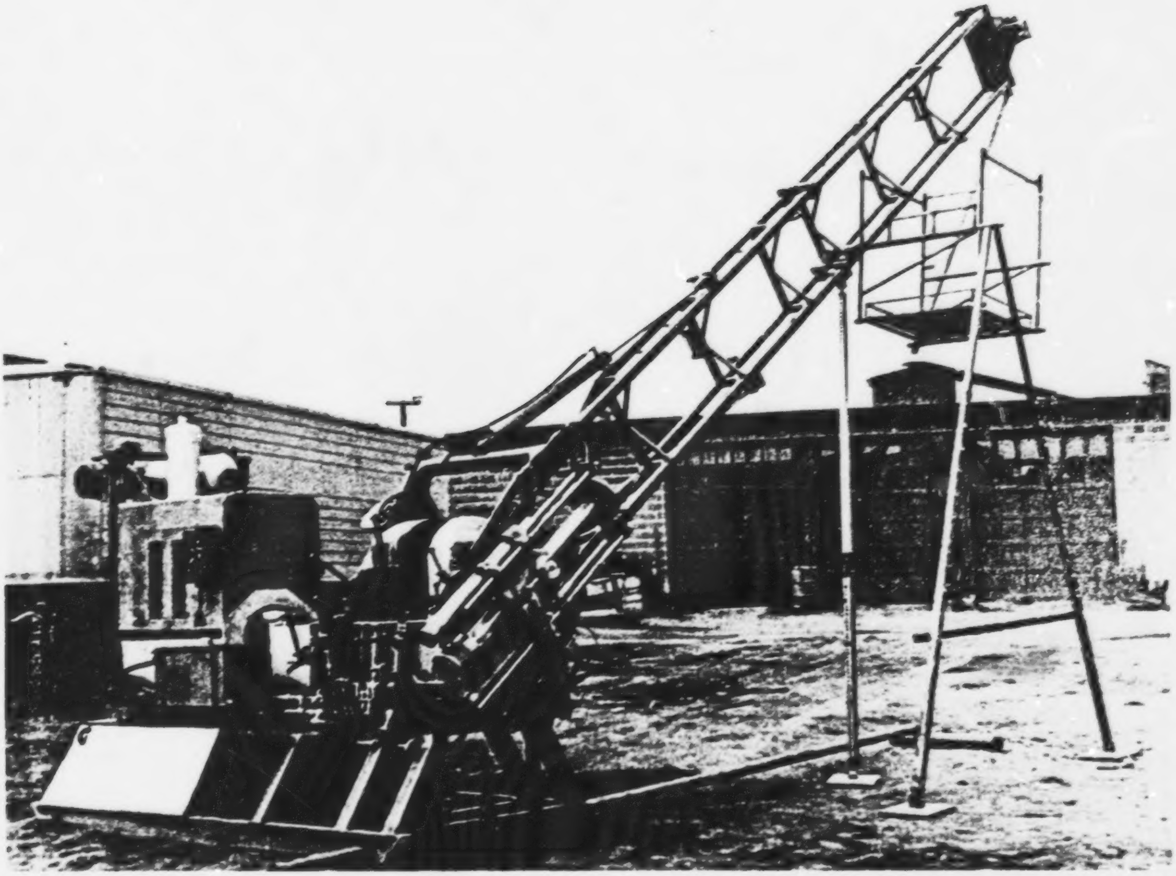


Fig. 3 - Sprague & Henwood Inc. Model 142C
Drill (Front End View)

Note The Hydraulically-Operated Derrick which compensates for drill offset when the drill is retracted.

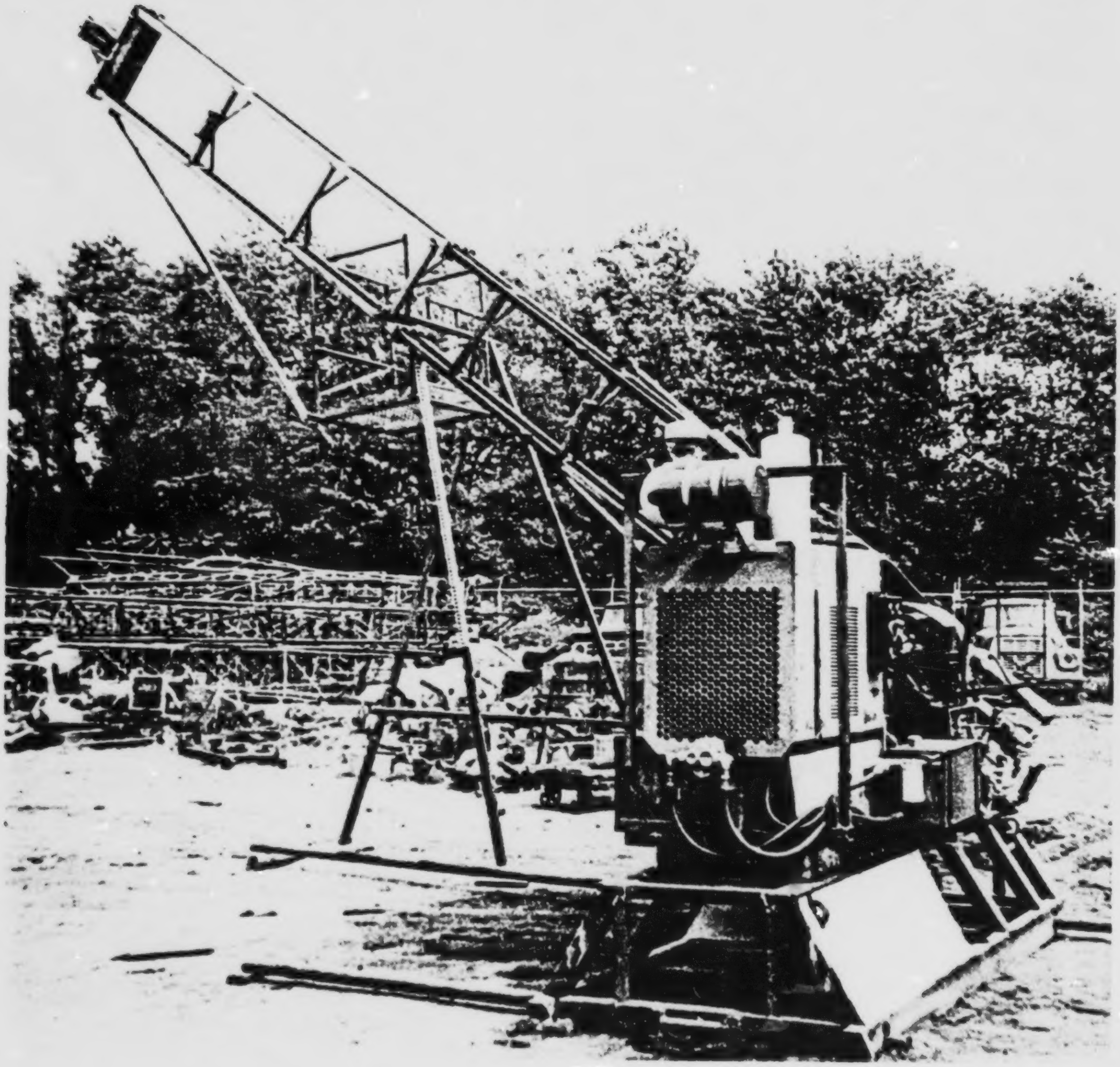


Fig. 4 - Sprague & Henwood Inc. Model 142 C Drill (Back End View)

of noise dampened steel in order to prevent them from acting as noise radiators as a result of structureborne vibrations. The treated engine operating outdoors by itself at 1800 rpm (i.e. the normal recommended speed) was found to emit 82 dBA when measured in the operator's position(11). This compares very favourably with the 80 dBA level observed in the case of the CANMET prototype. It should be noted, however, that the noise deflection panels located beneath the engine take advantage of air absorption to limit noise levels ultimately reaching the operator. This advantage would be lost if the drill were placed inside a drill shack, which is a common practice in Canada. Noise levels could be expected to rise by at least 5 dB in this event.

The second approach used by Sprague & Henwood is illustrated by Figures 5 and 6, and represents their "fully enclosed" unit. In this instance, a larger and custom-designed engine enclosure has been used, and acoustical panels have been extended forward on the operator's side of the drill so as to also shield the entire drive shaft and front end. The unit shown is a Model 40C, which is equivalent to a BBS-15. Only the head itself remains outside of the acoustical enclosure. Panels around the front end further reduced noise emissions from some of the gearing (discussed in more detail later). This arrangement, however, was not found to be practicable by operators after several months of operation because the extended panels hampered access to certain drill components during routine maintenance. The panels were eventually removed. Although quite independently designed, the engine enclosure itself bears a striking resemblance to the CANMET prototype, and incorporates the same basic features (i.e. acoustical absorption inside, combustion air and engine exhaust silencers, access panels, etc.). Note that a hydraulic pump which is mounted just below the radiator has also been built into an enclosure.

To date, Sprague & Henwood have manufactured one Model 40C drill, and two Model 142C units. The latter style appears to be most readily accepted by users, and also features a modified gear train as discussed later in Section 10.3.

9.4 Recent Improvements Achieved by St. Lambert Drilling Co. Ltd.

A Canadian drill contractor in Valleyfield, Québec, who also builds his own drills has recently implemented some advanced noise control design concepts for hydraulic drill rigs which were thought to be worthwhile reporting here, even though the class of drill concerned is different from that discussed so far. In this instance, the drill is completely hydraulic (i.e. hydraulic rotation, thrust and chuck), and is housed in a

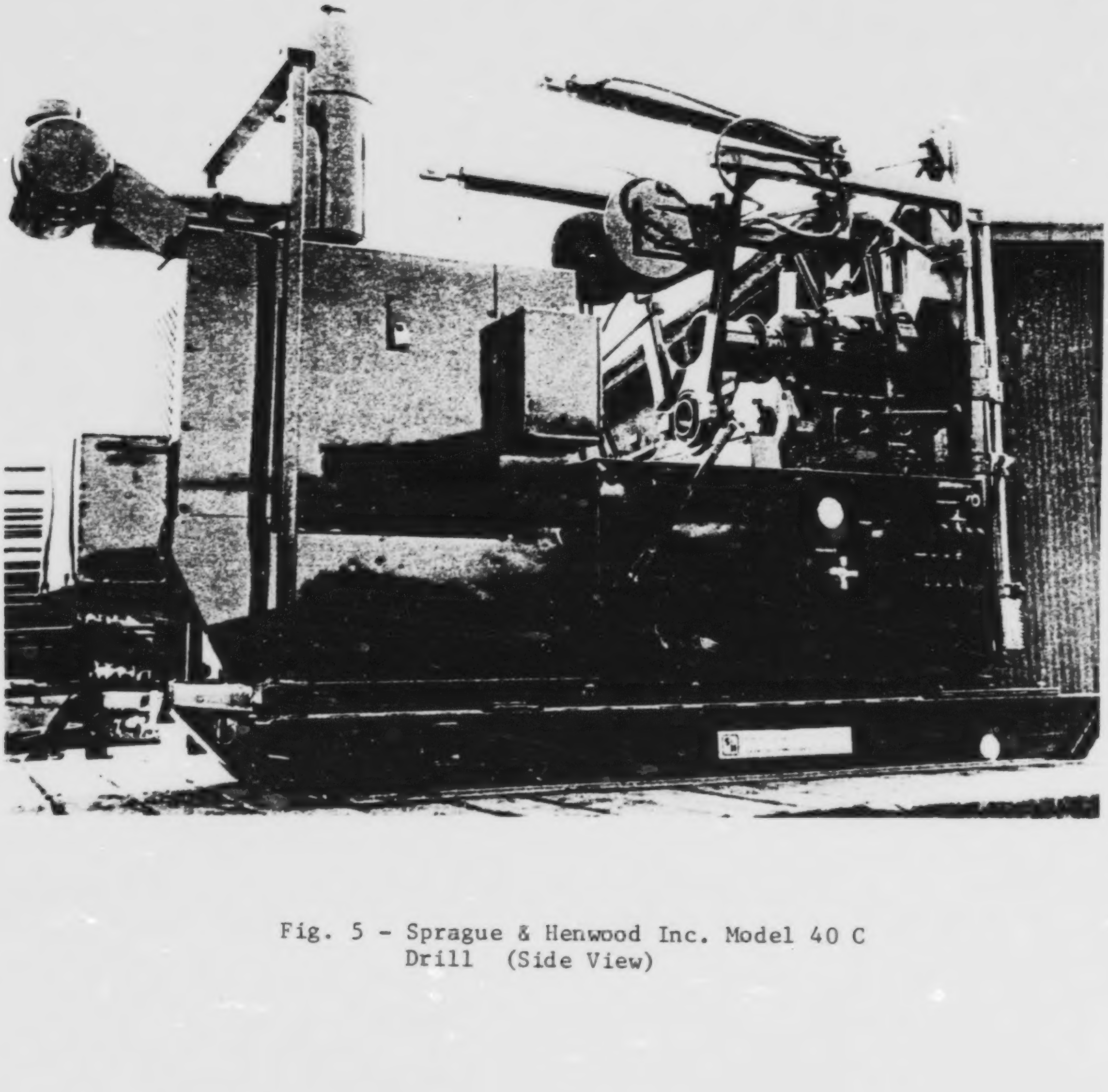


Fig. 5 - Sprague & Henwood Inc. Model 40 C
Drill (Side View)

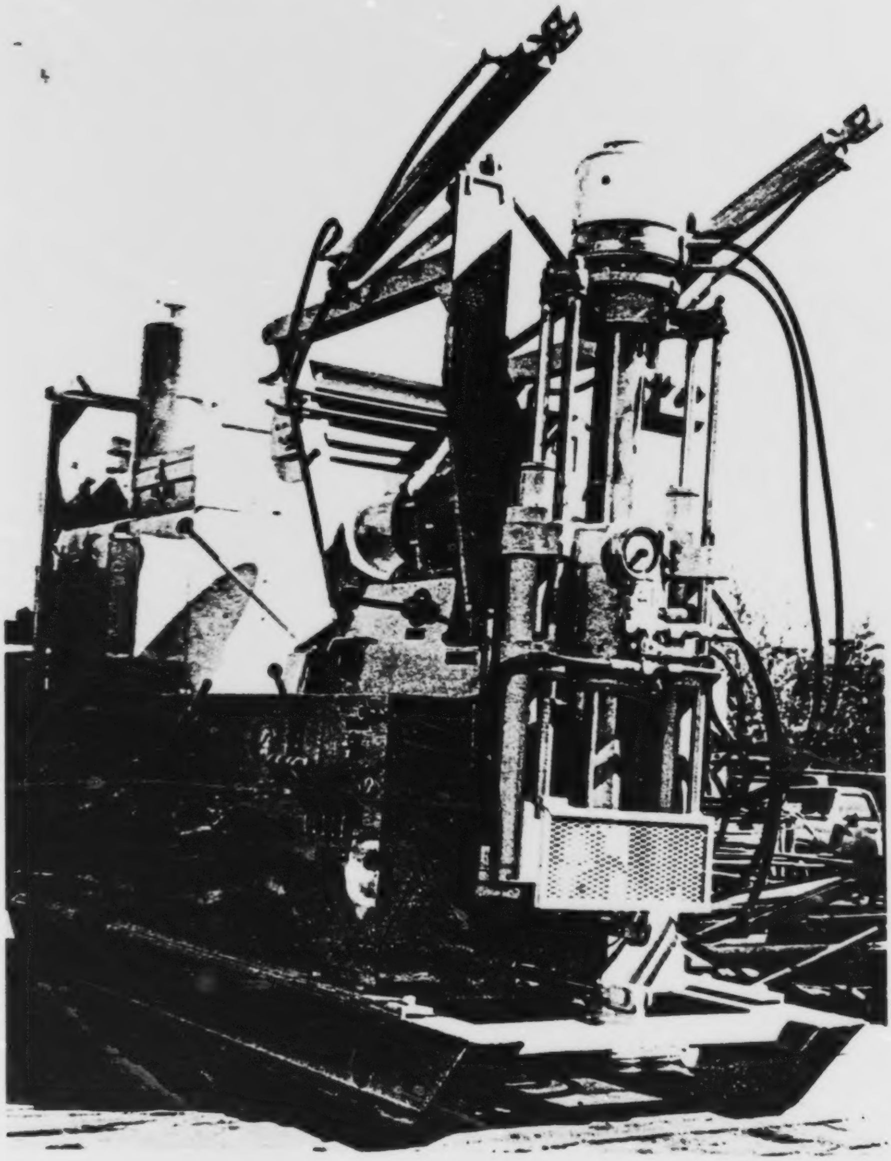


Fig. 6 - Sprague & Henwood Inc. Model 40 C
Drill (Front End View)

permanent drill shack as opposed to the disassembling type more typically found in Canada. Two models have been built to date, the SRS-900-1, which is powered by a five-cylinder air-cooled Deutz diesel, and the COPCO 251-1, which is powered by a four-cylinder Deutz. Apart from the difference in power packs, the COPCO 251-1, which is the latest of the two models, was equipped with a different clutch and a newer hydraulic head which is said to contain higher precision gears. Otherwise, the drills and shacks are virtually identical.

The overall layout of the shack and drill are illustrated in Figures 7 and 8. Note the outside access door to the engine compartment in Figure 7B which facilitates routine inspections. In Figure 8A is seen the acoustical engine compartment (lower right hand corner) and the perforated steel panels of the sound absorbent walls (2 in. thick fibreglass). Combustion air is ducted in from the rear wall of the shack, and cooling air is available through a grill in the rear wall. Heated air from the engine is directed into the cavity under a false floor, and filters up between the planking in the floor to heat the drill shack. Figure 8B shows the quiet-operating, hydraulically-powered water pump (Brama Model 24). Another noise control feature which was used but is not readily apparent from the above pictures was to restrict most of the high pressure hydraulic hose runs to the cavity under the false floor. With the exception of hoses going to the head assembly, all hoses above the floor (i.e. to the operator's controls, etc.) are low-pressure hoses.

With the configuration described above, the SRS-900-1 was found to run at 95-98 dBA in the operator's position depending on the elevation of the head on the drill boom, and the COPCO-251-1 was found to run at 92 dBA*. Additional measurements under the same conditions showed that the acoustical engine enclosure limited noise levels from either engine to approximately 82 dBA when operated in neutral and at 2350 rpm (maximum rpm for both engines). This figure is comparable to CANMET and Sprague & Henwood results. When the water pump was engaged, noise levels rose to 83-84 dBA on both models, and finally, the above quoted levels in excess of 90 dBA were observed when the head was engaged to commence normal drilling([15]). The improved gearing in the head of the COPCO-251-1 model appears to have been responsible for a noise reduction of 3 to 6 dBA observed in these measurements.

Subsequent measurements on the SRS-900-1 drill after approximately a year's operation in the field indicated that the noise control package had stood up very well, and that noise levels remained unchanged from when the drill was new. Noise

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* Drill shack roof panels and ventilation panel (on rear wall) were open during measurements. Shack door was closed. Both drills were new.

Fig. 7 - OUTSIDE VIEWS OF ST. LAMBERT DRILLING CO. LTD. MODEL SRS-900-1 DRILL SHACK

Fig. 7A - Typical Set-Up on Drill Site

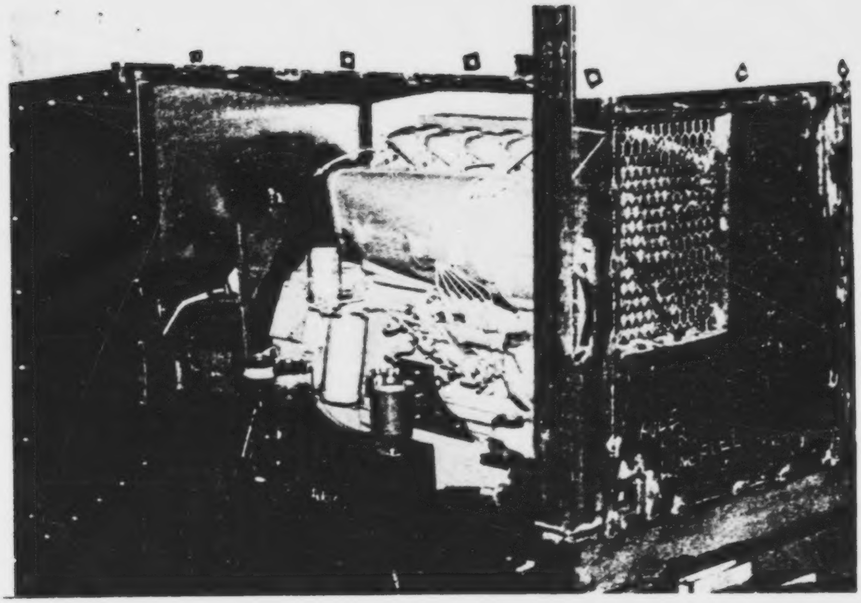

Fig. 7B - Outside Access Door to the Engine Compartment (Shack still under construction. Note cooling air intake & acoustically-lined engine compartment.)

Fig. 8 - INSIDE VIEWS OF ST. LAMBERT DRILLING CO. LTD. MODEL SRS-900-1 DRILL SHACK WHILE UNDER CONSTRUCTION

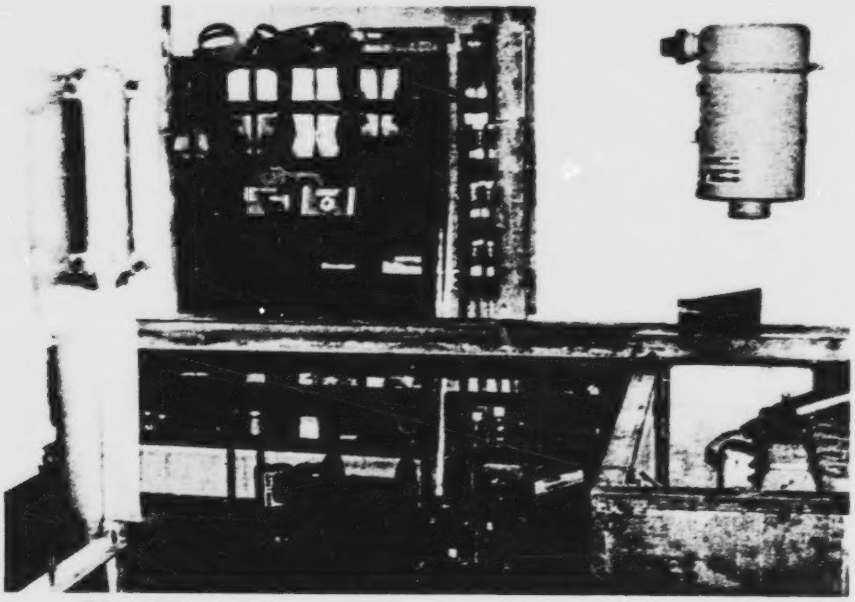

Fig. 8A - Views of Acoustical Engine Compartment (Lower Right Hand Corner) and Perforated Steel Panels of Sound Absorbent Wall

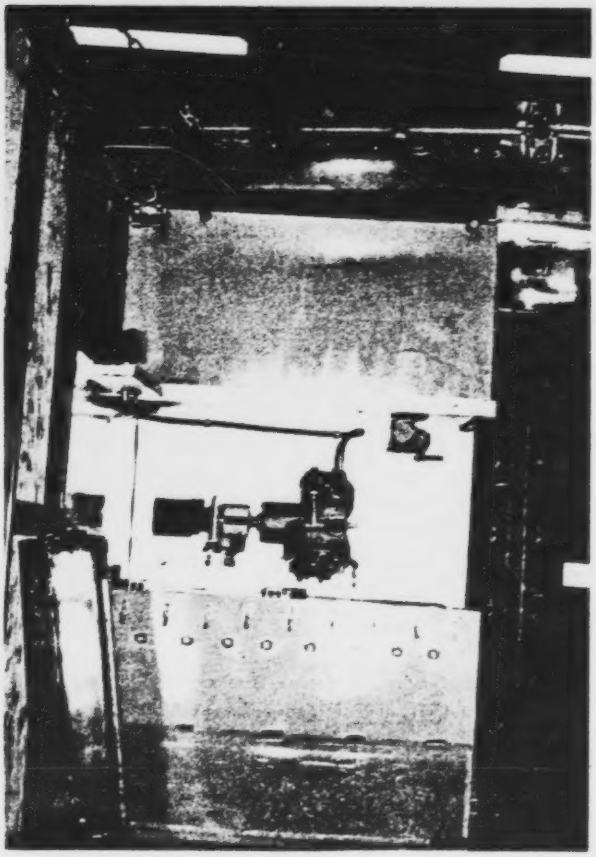

Fig. 8B - Quiet-Operating Water Pump

dosimetry on the drill operator indicated a typical average noise level (i.e. equivalent noise level, or Leq) while operating this drill on a routine day would be 94 dBA(16). This figure is lower than the 95-98 dBA level quoted above because it takes quiet periods which may occur over the normal working day into account. The implication of this average noise level is that an operator could be legally exposed to the drill noise without hearing protection for 4.7 hours daily instead of 2.7 hours as implied by the previous spot measurements. Of course, if hearing protection is worn, exposure time can be greatly extended, but is dependent on the wearing habits of the operator, and the efficiency of the hearing protectors used(17). It is worth noting here that the use of hearing protectors is not accepted by the authorities as a suitable long term noise control solution.

10. GEAR CONSIDERATIONS

10.1 Field Measurements on a Longyear 38

Previous noise measurements in the operator's position of a BBS-15 had shown that the principal noise sources were as summarized below in Table 3(2).

TABLE 3 - PRINCIPAL SOURCES OF NOISE MEASURED ON A BBS-15

(ref. the operator's position)

	Drill Rig Component	Type	dBA
1.	Power Pack	Deutz, 2 Cylinder (26KW/35HP) Air-Cooled, with Muffler	98
2.	Head Gear	Straight Cut Bevel	97
3.	Water Pump	Diesel-Powered	96.5
4.	Front End	Open Chain-Driven	95
		Overall	103

Discussion of these data with members of the Canadian Diamond Drilling Association Technical Committee raised some questions of whether the values shown for the head gear and front end were still valid since improvements had been made on newer models of the drill type used during the study.

The question of how accurately the initial set of data represented the noise characteristics of newer drilling rigs arose again in May, 1982, while meeting with a drilling contractor to obtain a user's impression of some preliminary thoughts on possible design changes to existing swivel heads. The contractor had a Longyear 38 rig sitting in the yard, and graciously consented to starting it up so that the author could listen for any noticeable differences between it and the older BBS-15. A subjective impression of the principal noise sources heard, in order of their importance, was the engine, front end, and head gears. The water pump was hydraulically powered in this instance, and was not audible in the presence of the remaining noise sources. Spot checks with a noise meter indicated that the overall level in the operator's position was 102-103 dBA. The relative importance of the noise sources was as follows: the engine first, the front end second, and the head gear third.* The fact that the front end was noticeably louder than the head gears was surprising, and indicated a need to carry out further measurements in order to determine if design changes being contemplated for the swivel head were indeed necessary.

A new study was carried out in September 1982, on a fairly new Longyear 38 operating near Pugwash, Nova Scotia. The rig is owned and operated by Mr. C. Smith, a sub-contractor to Logan Drilling Ltd. of Musquodoboit, Nova Scotia. The drill was approximately 1½ years old at that time, contained all its original parts, and appeared to be in excellent mechanical condition. It was powered by a four-cylinder Deutz air-cooled diesel (68 HP), which was equipped with an exhaust muffler and exhaust hose for routing fumes out of the drill shack. The shack was an 11 ft x 16 ft x 6 ft plywood construction with a roof that was mainly open, except for an approximately 2 ft wide "L"-shaped strip over the operator's normal work area, and a back wall that was open from roof height down approximately 2 ft along the entire length of the drill (see Fig. 9A). Size BQ rod (16 ft lengths) was in use, and hole depth was approximately 200 ft during the noise tests.

On-site noise measurements were carried out under normal drilling conditions using a GENRAD Model 1933 Precision Sound Level Meter and Analyzer equipped with a ½ in. electret condenser microphone with windscreen. Measurements were typically carried out near the engine (2 ft from engine in available space between engine and drill shack wall), at the drill controls (hereafter called the operator's position), and at a small bench in one corner of the drill shack where the operator occasionally rested when the drill was operating smoothly, and where noise levels were observed to be 2-3 dBA lower than at the controls. Noise levels obtained under most test conditions were also recorded on a Nagra Model SN tape recorder for subsequent analysis on a Nicolet Model 446B Real Time Spectrum Analyzer (RTA). The

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*Determined by measuring noise levels very close to each source (i.e. within 2 in.). Levels obtained were 110, 108 and 104 dBA for the engine, front end and head gears, respectively(18).

Fig. 9 - LONGYEAR 38 DRILL ON WHICH NOISE SOURCE RANK-ORDERING MEASUREMENTS WERE DONE

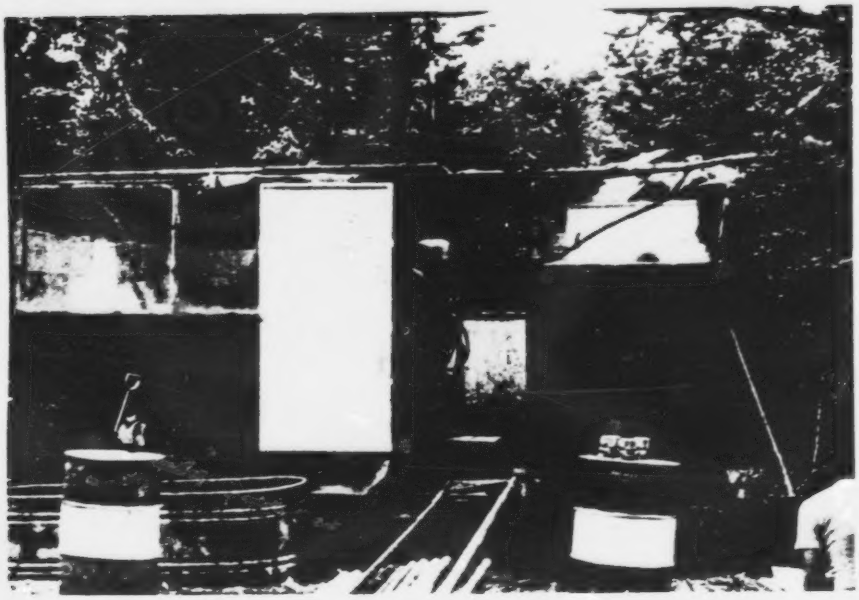

Fig. 9A - General View of Drill & Site

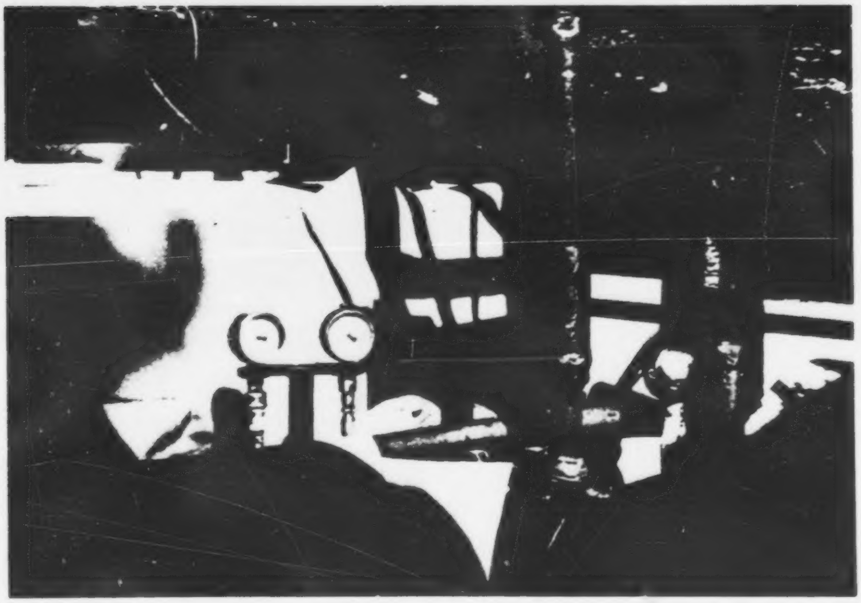

Fig. 9B - View of Temporary Engine Enclosure
Used During Measurements

latter data were found to be the most meaningful, and are therefore discussed further below. A limited amount of dosimetry was also carried out during the two days on site, using Metrosonics Type db-301 Profiling Dosimeters.

Narrow band (i.e. 400 line) noise spectra corresponding to three different modes of operation are shown in Figure 10. The three operating modes represented correspond to:

(i) Operating the semi-enclosed power pack at wide open throttle by itself (i.e. automotive transmission was in neutral). A crude acoustical engine enclosure was installed in the field (see Fig. 9B) in an attempt to suppress engine noise sufficiently to allow noise from other suspected sources to be measured directly. A 4 to 5 dBA reduction was obtained in the process, and corresponding engine data are labelled "isolated".

(ii) Operating the engine as before, but with the automotive transmission in fourth gear, and the head gear in neutral. Resulting noise levels should therefore represent the combined effects of the engine and front end.

(iii) Operating the engine and front end as before, but also engaging the head in high gear. Resulting noise levels should represent normal drilling conditions.

The ordinate of Figure 10 shows the noise levels observed for each case in dBA, and the abscissa shows the frequency content of each spectrum over the range 0 to 10,000 Hz. The A-weighting and frequency span applied to each spectrum approximate the response of the human ear, and are useful in helping identify which portion(s) of each spectrum is most offensive. The narrow band resolution helps identify which mechanical components of the system are responsible for the observed noise levels. It should be noted that the dBA noise level with which most readers are probably familiar in the assessment of noise problems is approximately the integrated value or summation of levels over the entire frequency range shown in Figure 10.

Inspection of Figure 10 from the bottom up shows that the effects of the front end and head are clearly discernible even in the presence of engine noise. The most obvious effects can be seen as the rise of a major peak at 4800 Hz when the front end was engaged (middle spectrum), and peaks at 2400, 6300 and 7700 Hz when the head was subsequently engaged (top spectrum). The net contributions of either the head or front end to the total noise energy are obtained by subtracting the engine component from each. This can be done electronically on most RTA's, and in this instance, yielded the results summarized in Table 4[19].

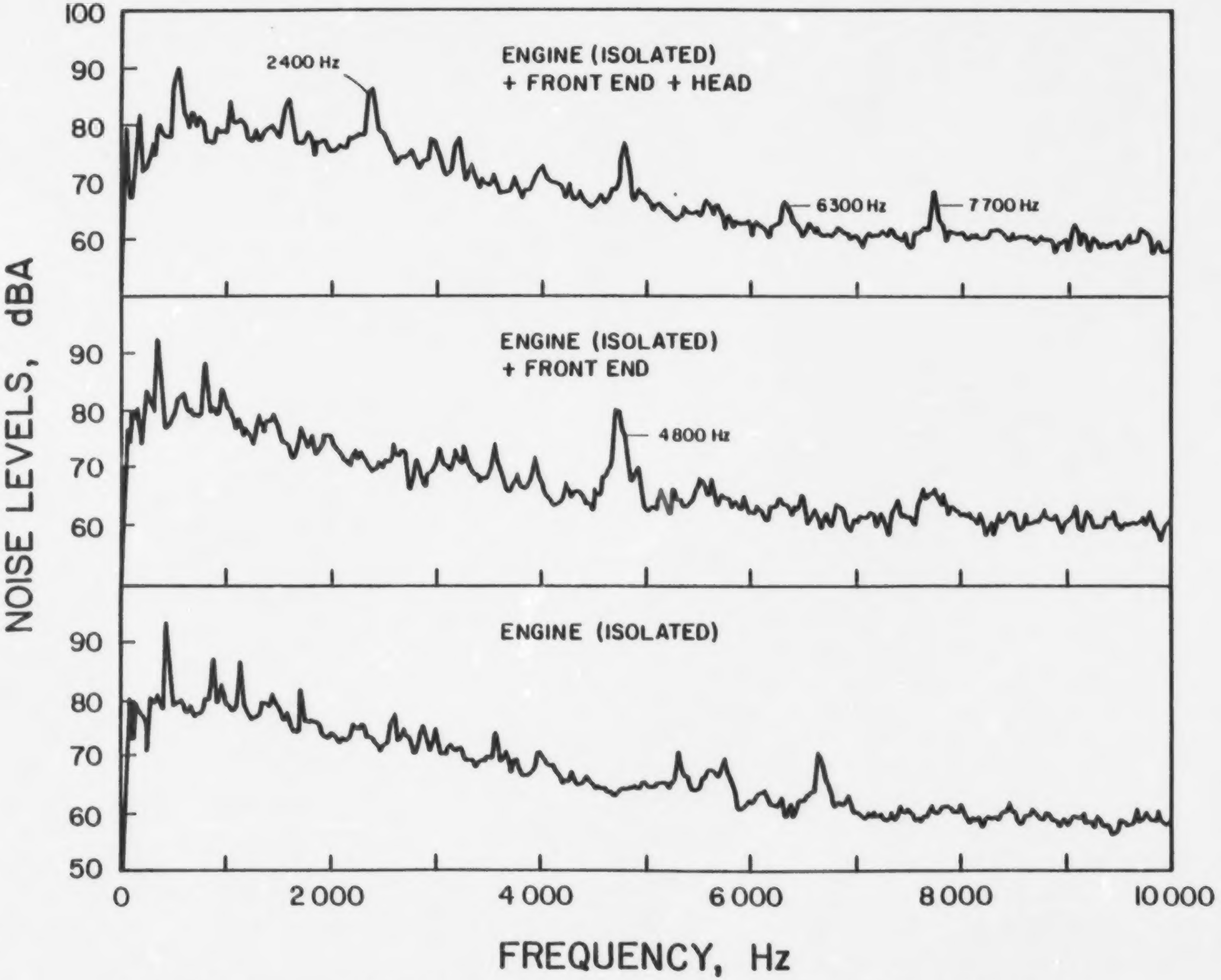

Fig. 10 - Longyear 38 Noise Spectra Corresponding to Several Operating Modes

TABLE 4 - RANK ORDERING OF KEY NOISE SOURCES ON A LONGYEAR 38

(ref. the operator's position)

	Drill Rig Component	Type	dBA
1.	Power Pack[1]	Deutz, 4 Cylinder (68HP/51KW) Air-Cooled, with Muffler	100
2.	Head Gear	Straight Cut Bevel	97
3.	Front End	Gear-Driven (Spur Gears)	91
		TOTAL	102

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[1] Included in the power pack noise emissions is a component from an auxiliary hydraulic pump mounted at the fan end of the engine which is used to power the water pump. Based on some incomplete test results, emissions from the auxiliary pump are suspected of being at about the same level as the power pack itself.

Comparison of Tables 3 and 4 shows that the older BBS-15 and newer Longyear 38 are very similar in terms of noise output. The gear-driven front end on the latter appears to be an improvement over the chain drive, but it still exceeds regulatory noise levels. Hence the need for continuing noise suppression work on front ends and heads is substantiated. Table 4 also confirms that a well-maintained front end should operate more quietly than the adjacent head. Evidence to the contrary encountered prior to this study is attributed to worn or poorly-lubricated gears in the front end.

Dosimetry measurements on the above Longyear 38 indicated that the typical cycle time required to drill a 16 ft length, exchange the inner tubes and start drilling again was 19 minutes.* Of this, the drill operated at wide open throttle (102 dBA) for 16 minutes, and idled at 90 dBA while exchanging inner tubes, etc. for 3 minutes. The average noise level (Leq) per cycle after taking the 3 minute pause into account was 99 dBA. This is equivalent to a noise dose of approximately 14% per cycle, (i.e. between rod changes) where 100% represents the maximum allowable daily noise dose without hearing protection. At the rate of three 16 ft cycles per hour, the maximum allowable noise exposure would be reached after approximately 2.5 hours of drilling. Actual noise exposures will vary with drilling conditions, number of delays encountered, etc. However, if the above rates were taken to represent the worst case, then noise doses which would be accumulated in 8, 10, and 12 hour drilling shifts would be 326%, 408% and 490%, respectively.

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* Includes drilling a 16 ft length with a 2 ft stroke on the drill, disconnecting the water swivel, lowering the overshot, pulling the inner tube, exchanging inner tubes, pumping an empty inner tube back down the hole, and lowering the rods for resumption of drilling.

10.2 Preliminary Study of Modified Head Options

Having determined that spur gears or a chain drive in the front end and straight cut bevel gears in the head were the next noise sources requiring treatment after the power pack, it became necessary to explore what design options existed for alleviating problems in both of the above sections of the drill. Plans called for: (i) preliminary ideas to be put forward on the basis of previous discussions with the C.D.D.A. regarding overall design constraints, (ii) selection of the most promising of these ideas for further consideration on the basis of discussions with interested drill users, and (iii) exploration of the latter in close cooperation with Canadian drill manufacturers with the goal of arriving at the definition of a likely design configuration and cost. Attention was focused on the head initially, since it posed the greatest challenge.

Two considerations were deemed important at the outset: (i) that the type of gearing currently used is not the quietest available, and (ii) that repeated opening and closing of the swivel head is likely to result in misalignment or changes in tolerance of the gear system and loss of proper lubrication, which in turn probably aggravates the noise problem. After careful consideration of these two major points, it was decided that if at all possible, any design modification should keep the head gears in contact, thereby maintaining proper alignment at all times even when removing corebarrels. This, of course could be easily accomplished if movement of the complete drill could be tolerated during the corebarrel pulling process. Following many discussions, it was determined that this procedure, although occurring infrequently, was not favoured by users. Therefore, it was necessary to find a technique which would provide easy core removal through swivel head movement, while still maintaining gear contact at all times. The type of gears to be used, subject to final design considerations, would probably be spiral or hypoid bevel gears.

A number of alternatives were considered on the basis of where the drills were to be used the detailed operations to be performed by the driller, the difficulties or restrictions imposed by these design changes the severity of the proposed changes (keeping retrofitting in mind), and the probable costs. Of all the alternatives considered, two were finally assessed as serious possibilities. These were:

(i) Telescoping of a closed head, using one of several possible linkages between the power shaft and head;

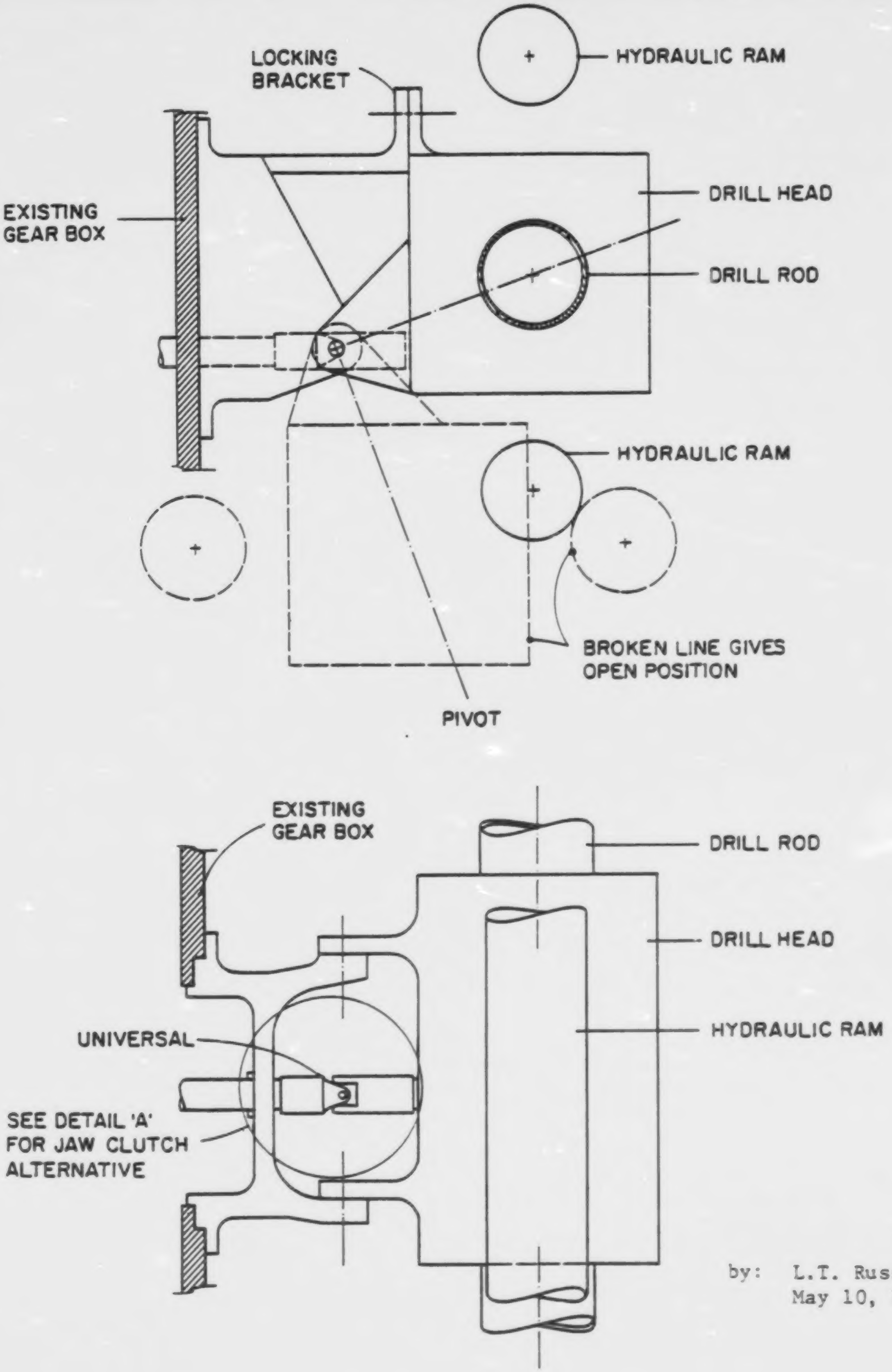
(ii) Swiveling of a closed head, using a universal joint in the power shaft to provide the linkage.

All of the above ideas were reviewed with personnel from a drilling contractor in order to obtain some user input before selecting the most promising options for further consideration. The second of the above approaches seemed preferable because it most closely resembled existing designs, and therefore seemed most likely to be accepted by drill users. Contractor personnel even suggested an alternate method for providing the linkage between the power shaft and the drill head(18). Before continuing with the preliminary design work, however, more detailed engineering data on the existing drills (e. g. power delivered through head gears, limits of allowable gear ratio changes, detailed dimensional drawings which would enable the particulars and practicalities of contemplated design changes to be examined, etc.) had to be obtained. This information was requested, but unfortunately never received. Nonetheless, engineering sketches suitable for discussion purposes and illustrating the two chosen approaches, were prepared on the basis of information previously received in the form of photocopies of manufacturers' parts lists and repair manual excerpts. These sketches are reproduced as Figures 11 and 12, and are explained below.

Both approaches incorporate the closed and swiveling head features. Spiral or hypoid bevel gears are to be used inside the head, depending on where the location of the pivot point for swiveling the head is ultimately chosen. Either gear set should operate more quietly than the existing straight cut bevel gears. Moreover, the closed head feature should also be quieter as a result of improved gear alignment, better lubrication and reduced wear. Alternate linkages between the power shaft and head are shown. The first (Figure 11), is the universal joint solution mentioned previously. Note the offset power shaft and pivot point required to implement the desired swiveling feature. The second (Figure 12), uses a jaw clutch in place of a universal joint, and could be used to eliminate the need for an offset power shaft and pivot point if necessary.

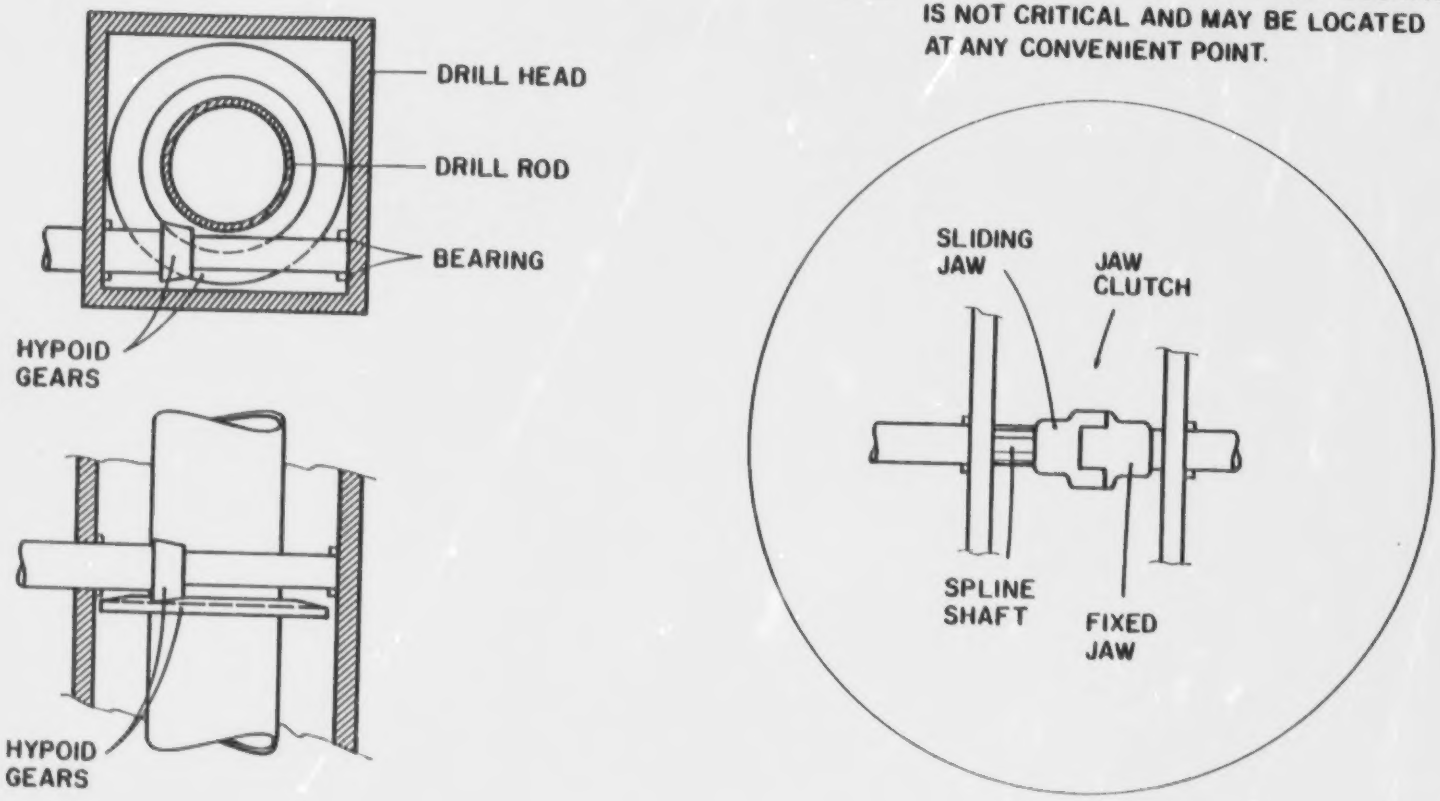
The above sketches were forwarded to the Technical Committee of the C.D.D.A. for comment by its members(20), but only one reply was received(21). This reply came from a drilling contractor, and raised several helpful and valid points about overall design considerations which were well worth further discussion with drill manufacturers, but posed no insurmountable problems so far as the basic concepts were concerned (particulars are included in Appendix D)(22).

An opportunity to review these concepts with Canadian drill manufacturers arose in September during a meeting of the C.D.D.A. Technical Committee in Toronto. The two suggestions were discussed in depth with all aspects of the design receiving attention. Possible difficulties with these designs such as extra cost, large overhang of the head, extra strength required,


LOCKING BRACKET
HYDRAULIC RAM
EXISTING GEAR BOX
DRILL HEAD
DRILL ROD
HYDRAULIC RAM
BROKEN LINE GIVES OPEN POSITION
PIVOT
EXISTING GEAR BOX
DRILL ROD
DRILL HEAD
HYDRAULIC RAM
UNIVERSAL
SEE DETAIL 'A' FOR JAW CLUTCH ALTERNATIVE

by: L.T. Russell
May 10, 1982

Fig. 11 - Closed Drill Head & Universal Joint Concepts


DRILL HEAD
DRILL ROD
BEARING
HYPOID GEARS
HYPOID GEARS
SLIDING JAW
JAW CLUTCH
SPLINE SHAFT
FIXED JAW

NOTE WITH JAW CLUTCH, PIVOT POINT LOCATION IS NOT CRITICAL AND MAY BE LOCATED AT ANY CONVENIENT POINT.

POSSIBLE DRILL HEAD GEARING ARRANGEMENT

DETAIL "A"

by: L.T. Russell
May 10, 1982

Fig. 12 - Drill Head Gearing and Alternate Power Shaft Linkage Arrangements

possible vibration in the head as a result of the changes, and the question of whether the changes could be incorporated into a retro-fit were all considered. A general conclusion seemed to be that the suggested design changes are technically feasible, but that a more in-depth study in cooperation with the manufacturer's designers will be necessary in order to determine the proper direction in which to proceed. Both manufacturers represented at that meeting felt that each company would probably cooperate with a more in-depth investigation, so a formal request to follow up with the required studies was made to each(23,24). Subsequent replies were somewhat less enthusiastic(25,26). As a result, a review of alternate approaches will be required in the future.

A lack of engineering details on front ends precluded any significant headway being made on the further study of possible design changes in front end gearing. Considerations in mind include substituting helical gears for the spur gears, use of "quiet" chain drives or chain drive shielding, etc.

10.3 Power Train & Head Options From Sprague & Henwood Inc.

Referring back to Figures 3 and 6, the front end and head assemblies for the Sprague and Henwood Models 142C and 40C drills can be seen. The Model 142C front end has been modified internally and fitted with a set of "quiet-operating" gears, details of which were not disclosed for proprietary reasons. The head has also been modified to accept a set of "carefully lapped" spiral bevel gears. By contrast, the front end of the Model 40C drill was left unmodified; however, the acoustical enclosure has been extended from the engine, along the drive shaft, up to and including the front end. The head was modified with a spiral bevel gear like that of the Model 142C.

Operating experience with both models has shown that the 142C is the more favoured of the two. The large engine enclosure and extended acoustical panels for the front end were found to be too bulky in the field and also encumbered routine maintenance. Some of these panels were finally removed by operating personnel, thereby defeating much of the noise control effort which had been made. However, the continued successful operation of the Model 142C is indeed very encouraging and demonstrates the technical feasibility of a compact acoustical engine enclosure and of quieter-operating gears in the front end and head. Both models are retractable drills with fixed heads. A unique movable tower feature has been provided on each model to compensate for offset created between the drill hole centre line and the sheave at the top of the tower when the drill is retracted.

Cost data for both models were also obtained and are discussed next. For now, it is worth noting that the total costs for all of the noise control options did not exceed $5,000 U.S. (or ~$6,000 CAN.). These figures barely account for the cost of materials and components involved, therefore indicating that substitution of quiet-operating gear sets must have been possible with very little change in the original gear boxes, and also demonstrate that retrofit noise contol is economically feasible.

Overall noise levels measured in the operator's position with the above noise control packages in place were 94.5 dBA on the Model 142C drill, and 90 dBA on the Model 40C(11). The difference in noise levels is believed attributable to residual noise from the front end, although this observation remains to be proven by actual measurement. This also suggests that additional work must be done on the front end if a design goal of 90 dBA or less is to be achieved ultimately. The 90 dBA minimum observed on the Model 40C drill appears to be determined by the spiral bevel gear, although again, the latter observation remains to be proven. The above may also be evidence of the lowest gear noise level achievable by simple gear substitution. Nonetheless, both drills have demonstrated a very significant improvement over the 100-107 dBA previously observed on drills currently in use in Canada.

11. CURRENTLY AVAILABLE NOISE CONTROL OPTIONS

When discussing available noise control options, a distinction has to be made between new drills and existing drills. Much more latitude exists in improving the design of new drills because in this case options like the use of hydrostatics to eliminate front end noise, or placing of the power pack in a remote location can be considered. Also, new drills with demonstrated noise control features (e.g. Sprague & Henwood) can be obtained commercially. Since the findings of this study suggest that retrofit noise control on existing drills is indeed feasible, the remainder of the discussion will limit itself to options currently available for drills in the latter category. This, of course, imposes severe design constraints in that all suggested modifications must be completely compatible with existing equipment, and must be capable of retrofitting in the field, usually by the drill user himself.

11.1 Power Pack Alternatives

There is no doubt that the drill's power pack is a major noise source. Proper silencing involves the use of an effective engine enclosure, and not just exhaust mufflers. Users may choose between building engine enclosures for existing engines themselves, having enclosures built on their behalf by acoustical equipment suppliers, or replacing existing engines with factory-silenced diesels such as the ones used in the Hatz series of "Silent Power Packs".

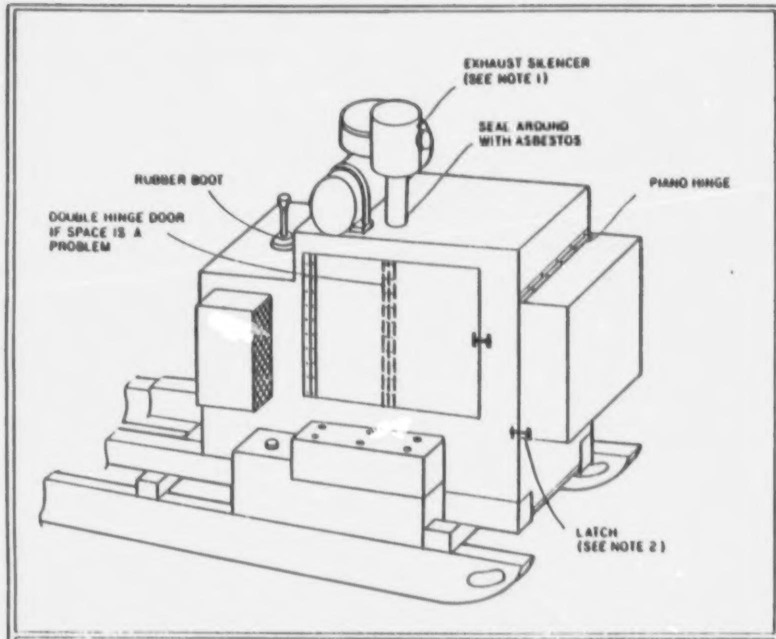
The salient features of the type of engine enclosure which could be fabricated and installed by users themselves are shown in Figure 13. In-house experience at Noranda has shown that an enclosure of this type could be fabricated and installed at a cost of approximately $5,000, including labour. Anyone choosing to go this route will require a limited amount of acoustical engineering supervision to ensure that when the general design of Figure 13 is adapted to a particular drill, the acoustical integrity of the enclosure remains intact. Experience has also shown that attempts to do without the recommended supervision usually results in technical oversights whose correction ultimately involves substantial extra project costs and frustrations.

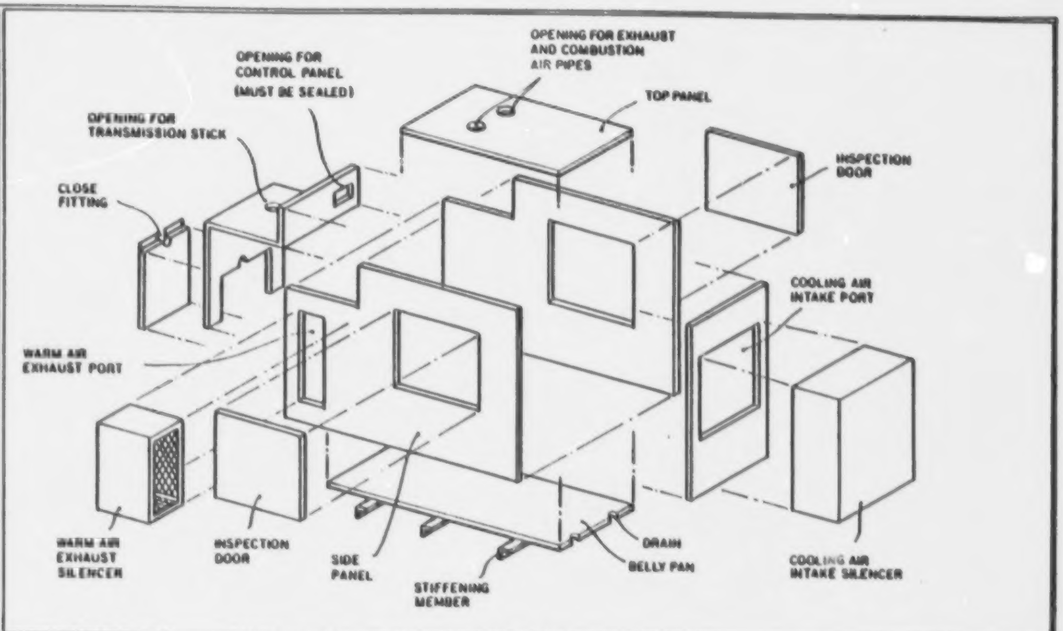
Preliminary quotations from acoustical equipment suppliers for the cost of providing a similar, although somewhat more complicated enclosure, indicated a probable cost of $12,000 per unit(2). This figure basically reflects the cost of adapting general purpose acoustical panels to a particular application, plus the cost of materials involved. Unless the acoustical equipment suppliers can amortize their engineering costs over a reasonable number of units, it is unlikely that the above price will ever be less. The probability of this happening is believed to be slight because most drill users tend to customize their drills in some way (e.g. by mounting auxiliary hydraulic pumps or water pumps onto the standard drill), which means that practically every engine enclosure will require customized fitting. Hence, engineering charges will necessarily persist.

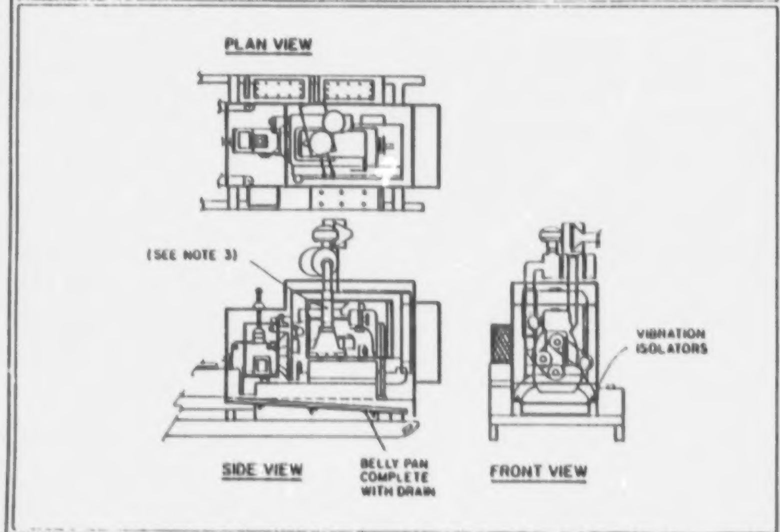
The cost of Hatz series L30 (30 - 60 HP) and L40 (40 - 80 HP) "Silent" diesels is in the order of $5,500 to $8,000, depending on the size of engine purchased, which is approximately 20 - 25% more than the cost of an equivalent regular diesel. If an existing engine needs replacing anyway, then purchasing a Hatz diesel already equipped with an engine enclosure would appear to be the most efficacious way of achieving power pack noise control. Otherwise, in-house fabrication of enclosures similar to that described in Figure 13 using outside acoustical engineering assistance as required would appear to be the best alternative.

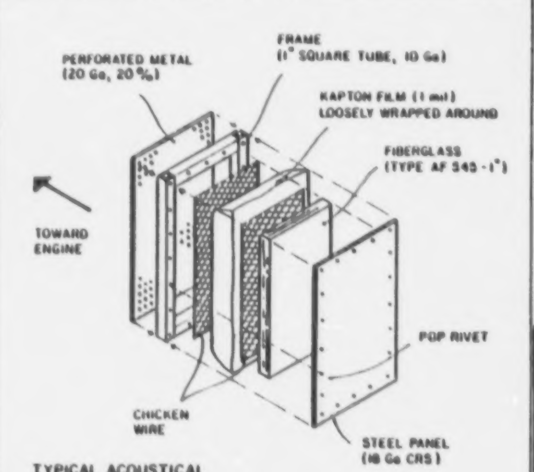
11.2 Front End Alternatives

Two approaches for treating front end noise have been demonstrated to date. One involves the use of acoustical panels to enclose most of the front end assembly, and the other the substitution of quiet (e.g. helical?) gears for the spur gears that are more typically found in front end transmissions. The former technique appears to have achieved the greatest noise reduction, but, unfortunately, was found to be impractical in the field. The latter technique has still to be demonstrated on typical Canadian drills. In addition, available data raise the question of how sensitive front end noise levels may be to proper


EXHAUST SILENCER (SEE NOTE 1)
SEAL AROUND WITH ASBESTOS
RUBBER BOOT
PIANO HINGE
DOUBLE HINGE DOOR IF SPACE IS A PROBLEM
LATCH (SEE NOTE 2)


OPENING FOR EXHAUST AND COMBUSTION AIR PIPES
OPENING FOR CONTROL PANEL (MUST BE SEALED)
TOP PANEL
OPENING FOR TRANSMISSION STICK
INSPECTION DOOR
CLOSE FITTING
COOLING AIR INTAKE PORT
WARM AIR EXHAUST PORT
WARM AIR EXHAUST SILENCER
INSPECTION DOOR
SIDE PANEL
STIFFENING MEMBER
DRAIN
BELLY PAN
COOLING AIR INTAKE SILENCER


PLAN VIEW
(SEE NOTE 3)
VIBRATION ISOLATORS
SIDE VIEW
BELLY PAN COMPLETE WITH DRAIN
FRONT VIEW


PERFORATED METAL (20 Ga, 20 %)
FRAME (1" SQUARE TUBE, 10 Ga)
KAPTON FILM (1 mil) LOOSELY WRAPPED AROUND
FIBERGLASS (TYPE AF 545 - 1")
TOWARD ENGINE
POP RIVET
CHICKEN WIRE
STEEL PANEL (18 Ga CRS)

TYPICAL ACOUSTICAL
PANEL CONSTRUCTION

NOTES:

ALL PANELS SHOWN IN EXPLODED VIEW (EXCEPT BELLY PAN) TO BE CONSTRUCTED AS PER TYPICAL ACOUSTICAL PANEL DETAIL. FINAL ARRANGEMENT TO BE SELECTED ON SITE.

1. EXHAUST SILENCER TYPE COWL TO BE PROPERLY SELECTED.
2. SOUTHCO INC. PART No. 37 - 10 - 086 - 10 OR EQUIVALENT.
3. COMBUSTION AIR INLET SILENCER ASSUMED, IF NOT ALREADY AVAILABLE ON DRILL, ONE MUST BE INSTALLED.

NORANDA RESEARCH CENTRE
POINTE CLAIRE, QUEBEC, CANADA

TITLE: ACOUSTICAL ENGINE ENCLOSURE FOR A DIESEL POWERED DIAMOND DRILL.

DRAWN BY: J. P. D.	APPROVED BY: P. NGUYEN	PROJECT No. N - 8235
SCALE: NONE	DATE: APRIL, 83	DRAWING No. 13

maintenance and lubrication (e.g. 91 dBA was measured on one Longyear 38, and 102-103 dBA on another). Although the use of quieter-operating gears in the front end appears to be the most promising route to pursue, potential technical problems relating to the required gear ratios, power transfer requirements, etc. remain to be explored, so specific recommendations cannot be made at this time. In light of Sprague & Henwood's positive experiences to date, a concerted effort to explore the full noise control potential of alternate gear sets should be considered in any future noise suppression studies on diamond drills.

11.3 Head Alternatives

Only one method of treating head noise has been proven to date, and it requires the use of spiral-cut bevel gears and a fixed head. Drill users have clearly expressed their preference for the retention of a swivel head over retractable drills (the only alternative at the moment) and preliminary studies have shown that provision of a swivelling, yet closed head assembly might be technically feasible, but will incur significant additional costs.

Until recently, all discussions with drill operators indicated that the only major drawback to switching to a retractable drill with a fixed head assembly, outside of potential cost, was the relative inconvenience of having to retract the drill as compared to simply swinging the head. Since most operators spoken to only had a need to swing the head two or three times per shift, switching to a fixed head seemed to be the most practical method of resolving bevel gear noise problems without unduly impacting current operating practices.

Discussions near the end of the contract period suggested another problem existed in connection with the drill tower, or derrick. It appears that the majority of surface drills in Canada have derricks which are attached to the drill itself. This feature facilitates alignment of the derrick and head assembly when drilling holes at angles other than 90° - which is usually the requirement in Canada due to the way mineralization most often occurs in the Precambrian Shield. Retraction of the drill under these circumstances will cause an offset to occur between the centre-line of the drill hole and the sheave mounted at the top of the derrick, thereby interfering with the pulling of the drill string. Thus, a means of compensating for the above offset is required.

Sprague & Henwood Inc. resolved this problem very nicely by installing pins at the base of the tower which allows the derrick to swing toward or away from the drill hole, all of which is supported on a yoke which allows rotation of the head and tower in unison for drilling angular holes. Movement of the derrick is controlled by two hydraulic cylinders (see Figure 3). The feasibility and cost of adapting similar designs to Canadian drills remain to be examined. However, the prospects of implementing similar changes appear favourable at this time.

Users will have to decide whether occasional retraction of the whole drill is a reasonable alternative to occasional swinging of the head. If so, then the introduction of spiral-cut bevel gears can probably be implemented in a fairly straightforward manner, and at a reasonable cost - although this view remains to be substantiated and should also be a part of any future studies on diamond drill noise control. The extent and cost of design changes to derricks will also have to be considered at this stage. If drill retraction is still deemed unacceptable, then suitable modified head assembly designs will have to be explored further with drill manufacturers, along with plans for eventually phasing out existing designs.

11.4 Water Pump Considerations

At least two methods of powering water pumps have been encountered on drills observed to date. One used a separate small diesel engine, while the other was driven by a hydraulic motor which in turn was powered by a hydraulic pump driven by the main diesel. In the former case, the water pump unit is a significant noise source and must be treated by means of an acoustical enclosure. A simplified version of the enclosure shown in Figure 13 should suffice. Depending on the pump's location with respect to the drill operator and shack, even simpler configurations may be possible.

The latter cases are not nearly so well defined. Noise emissions from the water pumps themselves or from the ancillary hydraulics were not discernible amidst the power pack, front end and head noise. Consequently, it is not possible to state with certainty at this time whether or not noise control will also be required on water pumps that are powered this way. The only advice which can be offered at this point is to include the water pump and hydraulics inside any newly installed engine enclosures, if convenient to do so, as a fail safe measure. Otherwise, one should wait until the need to treat this source has been substantiated.

11.5 Summary Of Cost Considerations

Sprague and Henwood have indicated the incremental costs for noise control treatments on their Models 142C and 40C drills to be $4,000 and $5,000 U.S., respectively (or approximately $4,800 and $6,000 CAN.).

On the Model 142C drill the above price includes:

- lining the standard John Deere engine enclosure with 1 in. soundfoam;
- one exhaust muffler;
- one combustion air inlet silencer;

- dampened-steel panels on the drill skid (beneath the engine);
- partial enclosures on two drive shaft couplings;
- vibration isolators under the engine and transmission;
- a "quiet" front end (i.e.with modified gear set);
- spiral bevel gears in the head.

On the Model 40C unit, the above price includes:

- a custom-designed acoustical engine enclosure;
- one exhaust muffler;
- one combustion air inlet silencer;
- vibration isolators under the engine and transmission;
- an acoustical enclosure around the power train and front end;
- spiral bevel gears.

Comparing the two drills, it is difficult to rationalize the small difference in price for the two noise treatments when one considers that the acoustical panels installed on the Model 40C unit obviously require much more material, cutting and fitting. Nonetheless, it is interesting to note that the cost of the more expensive treatment did not exceed $5,000.

Given the above figures, and the previous estimate for building an acoustical engine enclosure in-house, an estimated overall cost of $7 - 8,000 would appear to be a reasonable expectation for someone interested in installing his own engine enclosure and retrofitting existing gears in the front end and head with appropriate helical and spiral cut gears. This assumes that no significant changes have to be made to existing gear housings or derricks. Any costs associated with the latter would be extra. If a Hatz diesel were to be purchased instead of fabricating an enclosure for an existing engine, overall cost would rise to approximately $7,500 to $11,000, depending on the size of engine being purchased.

The purchase price of a new BBS-37, Longyear 38 or Sprague & Henwood 142C is approximately $50,000 ± 5,000 (CAN.$), depending on options selected. Assuming the purchase price of existing or future "silenced" diamond drills will never be less than $50,000, there would appear to be sufficient incentive for seriously considering retrofitting existing drills with noise controls. The margin is sufficiently large to also accommodate some expenditures on derrick modifications if necessary.

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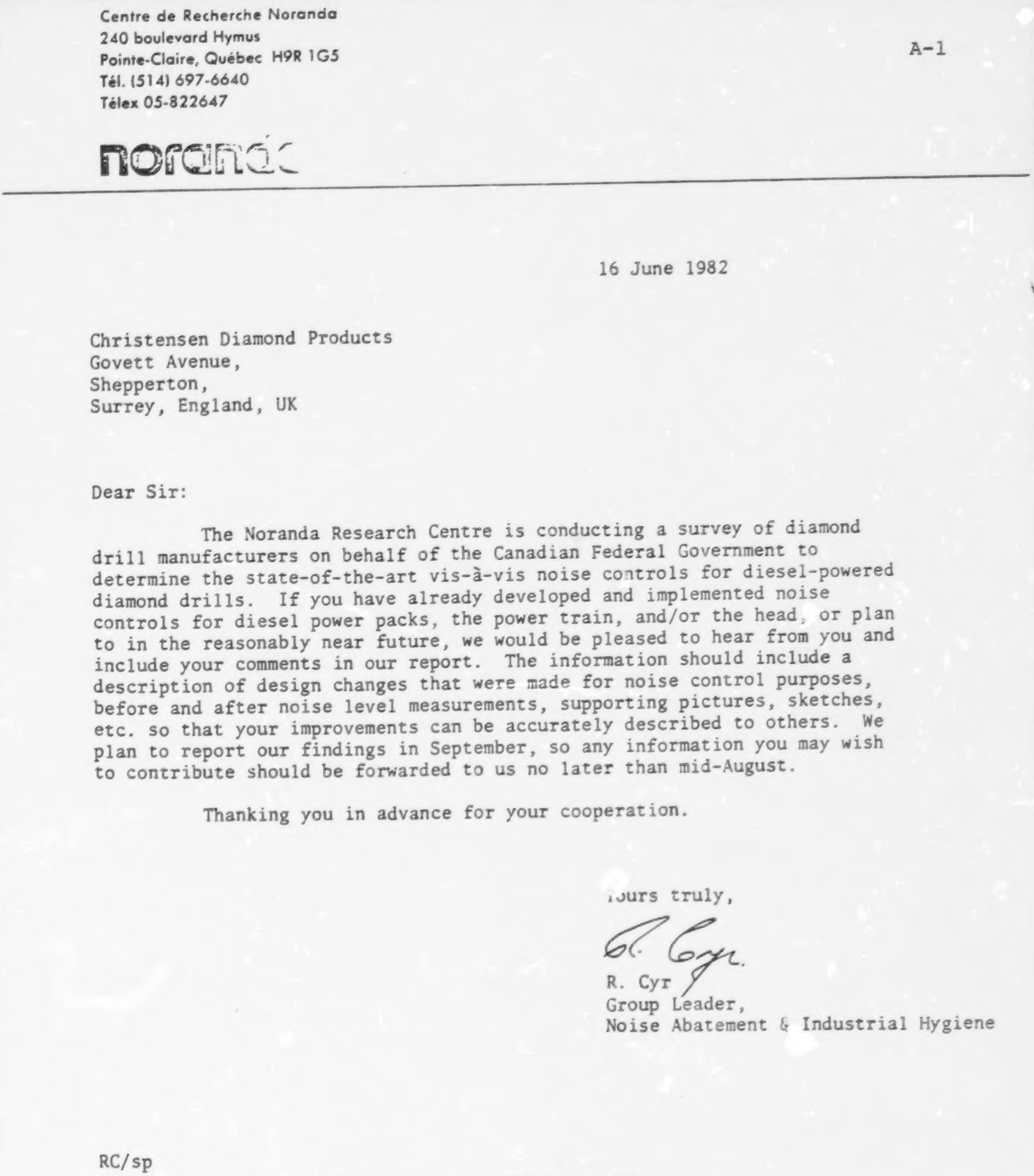
APPENDIX A

SAMPLE LETTER TO INTERNATIONAL DIAMOND DRILL MANUFACTURERS
&
SUMMARY OF REPLIES



Centre de Recherche Noranda
240 boulevard Hymus
Pointe-Claire, Québec H9R 1G5
Tél. (514) 697-6640
Télex 05-822647

noranda

16 June 1982

Christensen Diamond Products
Govett Avenue,
Shepperton,
Surrey, England, UK

Dear Sir:

The Noranda Research Centre is conducting a survey of diamond drill manufacturers on behalf of the Canadian Federal Government to determine the state-of-the-art vis-à-vis noise controls for diesel-powered diamond drills. If you have already developed and implemented noise controls for diesel power packs, the power train, and/or the head, or plan to in the reasonably near future, we would be pleased to hear from you and include your comments in our report. The information should include a description of design changes that were made for noise control purposes, before and after noise level measurements, supporting pictures, sketches, etc. so that your improvements can be accurately described to others. We plan to report our findings in September, so any information you may wish to contribute should be forwarded to us no later than mid-August.

Thanking you in advance for your cooperation.

Yours truly,

R. Cyr

R. Cyr
Group Leader,
Noise Abatement & Industrial Hygiene

RC/sp

FIGURE A-1 - Sample Letter
To Diamond Drill Manufacturers

TABLE A-1 - DIAMOND DRILL MANUFACTURERS SURVEYED REGARDING EXISTING OR PLANNED NOISE CONTROLS

OMPANIES	REPLY RECEIVED ?	NOISE CONTROLS DESCRIBED & COMMENTS
Atlas Copco Canada Ltd. Montréal, Québec	Yes	No longer manufacture complete diamond drills, only some components.
Acker Drill Co. Scranton, PA.	Yes	Spiral cut bevel gear inside a fixed head. No performance data available. Interested in Canadian progress.
Becker Drills Inc Denver, CO	No	
Boart International Windsor, England	Yes	Referred author to Longyear Canada Inc., an affiliate.
Bucyrus-Erie Co Milwaukee, Wis.	No	
Christensen Diamond Products Surrey, England	Yes	Do not manufacture drills, but indicated British Drilling Association will include noise as a required specification in a proposed "Drill Rig Rating". Expressed interest in Canadian progress.
Craelius AB, Bromma, Sweden	Yes	Provide option of sound-proofing on remote power packs for smaller (ie. 400m) hydraulic drills. Expressed interest in Canadian progress.
Diamant Boart Brussels, Belgium	No	
Dresser Industries Canada Ltd. Orillia, Ont.	Yes	No new developments.
Drill Systems Inc. Calgary, Alta.	Yes	Have used helical gears and pressure lubrication in the main gearbox of a dual tube drilling rig Also substituted hydraulics for a chain drive, muffled the power pack exhaust, and remotely locate both the power pack and compressor package. No performance data available.

(TABLE A-1 Cont'd)

11. Duke & Ockenden Ltd. Sussex, England	Yes	Provide sound-proofed power pack option on their hydraulic drill
12. English Drilling Equipment Co. Ltd., Yorks, England	Yes	Currently examining prospects of providing sound-proofed power pack.
13. Fox Manufacturing Co. Smithfield, Australia	No	
14. Longyear Canada Inc. North Bay, Ontario	Yes	Have experimented with gears in gear train, but particulars remain unspecified.
15. Mobile Drilling Indianapolis Ind.	Yes	Provide engine exhaust muffler upon request and label drills with warning sign indicating hearing protection must be worn. Expressed interest in Canadian progress.
16. Moss (Pty.) Ltd. Mt. Hawthorn, Australia	No	
17. Salisbury & Dietz Inc. Spokane WA.	No	
18. Smith International Inc. Newport Beach, CA.	No	
19. Soding & Halbach; Hagen Fed. Rep. Germany	No	
2 . Sprague & Kenwood Inc. Scranton, PA	Yes	Will provide complete drill enclosure or engine enclosure only. Will also provide helical gears in front end and spiral cut bevel gears in a fixed head. Expressed interest in Canadian progress.
21. Stork BV, Haarlem, Netherlands	Yes	Do not manufacture diamond drills.
2 . Thiele, Wilby, Bohrunternehmen, Bremer, Fed Rep. Germany	No	
23. Van-Moppes, Idp. Ltd. Gloucester, England	No	
24. Walkes-Mear Manufacturing Wichita Falls, TX.	No	

APPENDIX B

SAMPLE LETTER TO DIESEL ENGINE MANUFACTURERS

&

MANUFACTURERS' REPLIES

Centre de Recherche Noranda

240 boulevard Hymus
Pointe Claire, Québec H9R 1G5
Tél. (514) 697-6640

Twx 610-422-3026
Telex 05 24352 NORANDA MTL

noranda

7 April 1982

Mr. J. Stimson
Noise Engineer
Deutz Diesel (Canada) Ltd.
90 Montée de Liesse
Ville St. Laurent, Québec
H4T 1N4

cc: L. Geller (Canmet)
K. Wheeland

Dear Mr. Stimson,

Our Research Centre is conducting a study of engineering noise control methods for diamond drilling equipment on behalf of the Canadian Federal Government. We find that the class of drill most extensively used across Canada is powered by air or water-cooled diesel engines, typically in the 50 to 100 HP range. Perhaps not too surprisingly, we also find that the power pack is one of the key noise sources.

An acoustical engine enclosure is being developed as a retrofit package for existing drills. However, we were wondering if there would be any prospect of eventually expecting a 'quiet' diesel engine of this size range on the market (ie. one whose noise emissions do not exceed 85 dBA). Such an engine would obviate the need of, and added maintenance and costs associated with, an 'add-on' noise control package.

I would appreciate your comments concerning your company's existing or planned R & D programs in this area, along with some indication of probable timing re product availability, if indeed a program is underway. This information will be included in our final report at year end.

Looking forward to hearing from you, I remain,

Yours truly,

R. Cyr

R. Cyr, Group Leader,
Noise Abatement Technology and
Industrial Hygiene.

RC/sp

Detroit Diesel Allison
Division of General Motors Corporation

General Offices
13400 West Outer Drive
Detroit, Michigan 48228
Phone: (313) 592-5000
Telex: 234019
TWX: 810-221-1649

June 1, 1982

Mr. R. Cyr
Noranda
240 Boulevard Hymus
Pointe Claire, Quebec
H9R 1G5

Dear Mr. Cyr:

Please find enclosed the noise data you requested from General Motors on April 7, 1982. The data reflects projections for our line of small industrial diesel engines. Thank you for including us in your study.

Sincerely,

Tedd D. Grulke

Enclosure
TDG/jm

PROJECTED NOISE LEVELS FOR FORWARD PLAN

INCLUDES: ISOLATED ROCKER COVER & OIL PAN, CROSSHEAD PISTONS & OTHER ENGINE TREATMENTS.

CURRENT ENGINE	db(A)	PERCENT REDUCTION	REDUCED SPEED EFFECT	db(A)	PERCENT REDUCTION
3-53T @ 2500	93.0	56	3-53T @ 2200	91.0	37
4-53T @ 2500	97.0	62	4-53T @ 2200	95.0	37
6V-53T @ 2500	96.0	59	6V-53T @ 2200	94.0	37

BARE ENGINE S.P.L. MEASURED @ 1 METER PER SAE J-1074

A133

B-4

Ford of Europe Incorporated
Industrial Products Engineering

Arisdale Avenue
South Ockendon Essex RM15 5TJ
Telephone: South Ockendon
(0708) 853434
Telex: 995511

June 11, 1982

Centrede Recherche Noranda
240 boulevard Hymus
Point Claire
Quebec H9R 1G5
Canada

Attn: Mr R Cyr

Dear Sir,

Thank you for your letter of 7th April 1982 which has been passed to me for action.

There is increasing pressure in the field to reduce noise emanating from industrial equipment and legislation is progressively more stringent. In order to comply with such conditions most manufacturers find that improvements in equipment design must be made on a continuing basis in addition to that required for other reasons.

Ford Motor Company has recently introduced the 2720 Range of diesel engines to replace the 2710 Range with significantly reduced noise emissions.

The new 4 cylinder engine known as the 2722 which is most likely to be in the power range you require, has a 3m noise figure in the low 90's dB(A) depending upon speed. This is still somewhat above your target. Furthermore the engine requires a cooling fan, which is usually a major noise source compared to the engine and will drive a compressor hydraulic pump or other such equipment which could contribute significantly to the overall noise level.

As far as the future is concerned Ford Motor Company will of course endeavour to tailor its products to meet market and legislative requirements but I am not in a position to give you any particular details.

Yours faithfully,

K J Winter
Installation Engineer
Industrial Products Engineering

cc: J S Brown D-MW/GS-20
J C Moss GB-11/129

Telephone Extension 2519 Mailing Reference (Please include in Envelope Address) 20/589

Incorporated with Limited Liability in the State of Delaware, U.S.A.

B-5

HATZ GMBH CO KG
RUHSTORF a.d. ROTT

HATZ
DIESEL

Telefon Pocking (08531) 3021
telex Verkauf/Buchhaltung 057260
telex Einkauf/Konstrukt. 057268
Draht: Hatzmotor Ruhstorfadrott
Bahnstation Ruhstorf

Bayer. Vereinsbank Passau. Kto.-Nr 2817780, BLZ 740 200 74
Dresdner Bank Regensburg, Kto.-Nr 1915071, BLZ 750 800 03
Kreissparkasse Ruhstorf Kto.-Nr 570 100 800, BLZ 740 500 00
Deutsche Bank Straubing, Kto.-Nr 98/21 471, BLZ 742 700 15
Postscheckkonto München 1500-807

MOTORENFABRIK HATZ GMBH
D-8399 RUHSTORF a. d. ROTT

Ihre Zeichen Ihre Nachricht vom Unsere Zeichen 8399 Ruhstorf
Betreff MK/ME/Hör/ko November 24,1982

Subject: SILENT POWER SYSTEM
Engine Families L 30 / L 40

Ladies and Gentlemen:

To the already existing SILENT POWER SYSTEM engines we have added further three engine types which now cover a range of 10 to 50 kW (approx. 15 to 70 HP).

Enclosed you will find the new leaflet of our SILENT POWER SYSTEM. With this letter we like to repeat once more the outstanding features of this engine series:

1) Whatever your needs may be, one of our six engines in the range of 10 to 50 kW can always offer you an optimum in price and performance. There is no other manufacturer who can offer you a similar density in this HP-range.

2) A significant data and a measurement for the ability of an engine to operate safe and reliable on high speeds is the mean piston speed. The L 30 / L 40 engines are designed to feature a low mean piston speed of only 10/10.5 m/sec at 3000 r.p. m. (compared to 12 m/sec for engines which have, for example, a stroke of 120 mm). This makes the L 30/ L 40 engines so durable when it comes to applications where high speed is required.

3) A wide range of additional equipment is offered for the L 30 / L 40 engine family which is individually adaptable for various applications. This is not only true for stationary application but also for mobile machinery, using hydraulic drives. We offer, for example, a hydraulic oilcooler with an electric fan which provides the full cooling performance, independent of engine speed. The electric fan needs only 10 to 20 % of the

alternator performance which still leaves you sufficient output to cover all remaining electric consumers.

4) The noise reduction of the encapsulated SILENT PACKS is most evident by the following example: 10 SILENT PACKS do not make more noise than one conventional Diesel engine! Wherever strict noise regulations apply, the SILENT PACK offers the perfect solution. The maintenance- and service points of a SILENT PACK are just as accessible as they are for any other HATZ Diesel engine.

5) The engine family L 30 / L 40 is developped with view to future legislation on protection of the environment. Not only with regard to noise but also the exhaust gas pollution is kept to a minimum. Furthermore, the engines feature a closed crankcase breathing system, as there are some countries which do no longer allow crankcase breathing into the free atmosphere.

6) Most modern production technology paired with a high standard quality control system ensures a high reliability.

Last, but not least - a most important point when choosing a Diesel engine is also the service which can be offered. HATZ Diesel engines are taken care of through our network almost all over the world!

Yours sincerely,

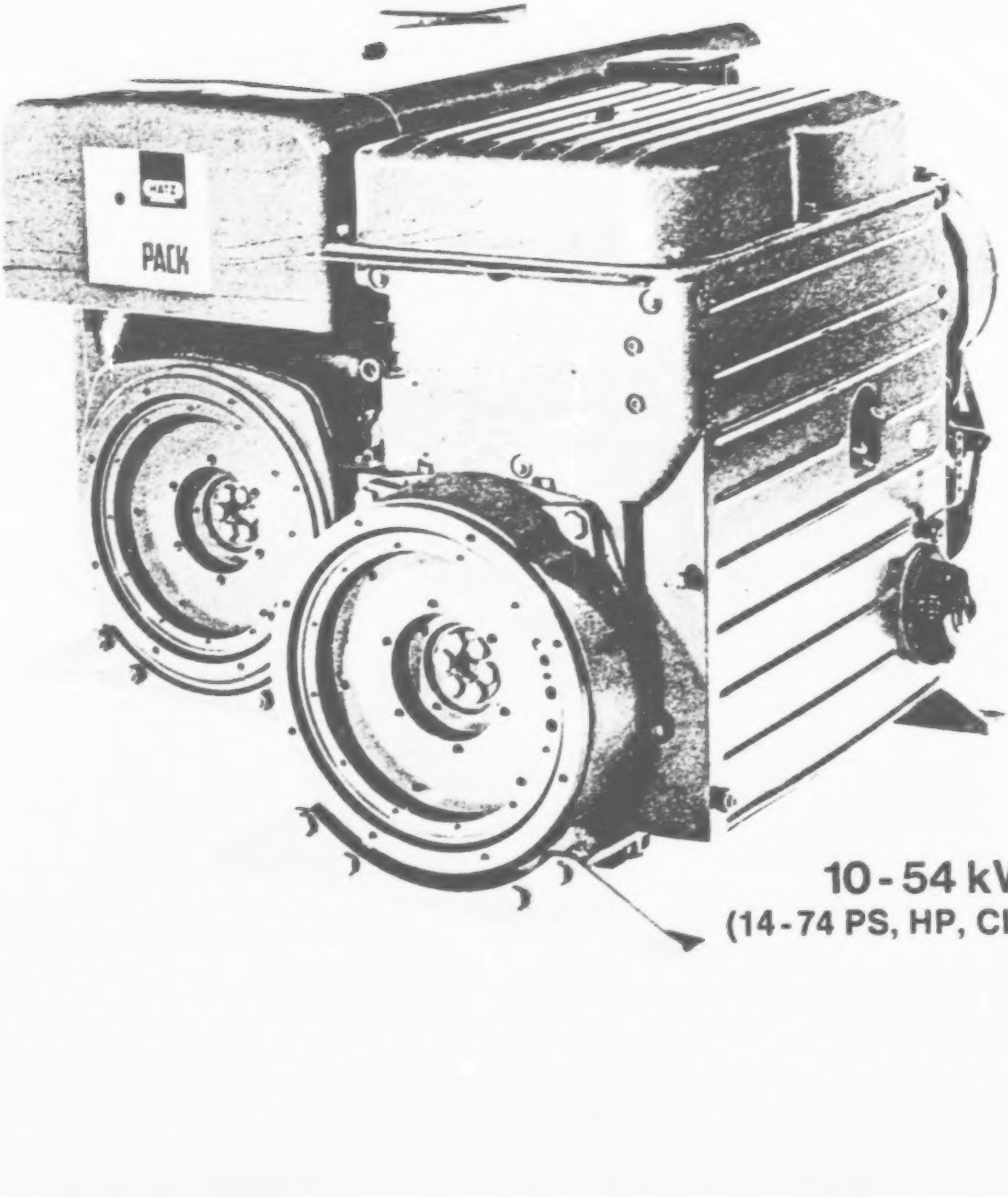
MOTORENFABRIK HATZ
GmbH & Co. KG

ppa. i.V.

C. Steppacher J. Horner

Enclosure
Leaflet
SILENT POWER SYSTEM

HATZ SILENT PACK



10 - 54 kW
(14-74 PS, HP, CH)

APPENDIX C

DETAILS OF PROTOTYPE ENGINE ENCLOSURE BY CANMET

DETAILS OF PROTOTYPE ENGINE ENCLOSURE BY CANMET

So far CANMET has built one prototype version of a sound-suppression enclosure around the entire diesel-engine cum automotive transmission unit on loan, including the diesel-fuel and hydraulic-fluid tanks, battery, etc. Close liaison was maintained throughout, and much helpful advice received from, the acoustics section of NRC's division of physics, from C.D.D.A. members (representing both their manufacturing and contracting membership) and the project-contractors (Noranda Research).

Overall details of the sound-enclosure in question are illustrated in Figs. C-1 to C-13.

Salient features are as follows:

a) A 48" x 120" x 3/8" steel plate is placed underneath the entire diamond-drill assembly, shaped somewhat like a "stone-boat" (Fig. C-1).

b) Six anti-vibration pads are placed between the 3/8" base plate and the unit's main supporting skids (Fig. C-5).*

c) Panels of the enclosure are constructed of 16 ga. sheet metal, lined on the engine-side with 1 in. thick fibreglass, the latter being retained by an expanded-metal mesh. One large panel on each side is readily removable for easy engine access (Figs. C-11 to C-13).

d) To allow radiator cooling-air to enter and leave the enclosure without noise emission, offset ducting passages ensure that there is no direct line of sight between the panel openings and the noise source. Also duct length to maximum duct width is about 3:1, and the passages are fibreglass lined. Duct cross-sectional area to radiator-area is about 2:1. The same design principles apply to the combustion-air inlet duct (Figs. C-1 & C-2).

e) The entire enclosure is mounted on the 3/8 in. base-plate, i.e. an effort was made to decouple the enclosure from the vibrating components.

---

* These were subsequently replaced with 4 pads between the engine and skid.

f) Bulkhead fittings are mounted wherever hydraulic hoses pass through the enclosure.

g) The enclosure is designed for relatively easy assembly and disassembly. Rugged field operating conditions, mobility and space-limitations have also been considered, as far as was possible at this preliminary stage.

As a general guide to future efforts in this area, it may be noted that by April 1982 CANMET had invested about 792 man-hours of labour and $1,900 in material costs to build and test this enclosure, i.e. some $11,000 overall. However, of this amount about 120 man-hours were spent in overcoming difficulties experienced when direct coupling the diesel to the test-dynamometer. As for some of the major material costs, the original six vibration-pads cost some $317, muffler and exhaust piping $349, hose-fittings $112, Kapton sheeting $280, fibreglass lining $65, Marinite sheeting $108, 3/8" base-plate $214, 16 ga. sheeting $223, expanded metal $141 and welding electrodes $44.

The sound proofing qualities of the enclosure were tested by removing the BBS-37 diamond-drill unit and direct coupling the sound-canopy enclosed GM 353 plus automotive transmission unit to an electric dynamometer (Figs. C-7 to C-10). The principal test objectives were to determine the overall noise level as a function of diesel engine speed and loading. Moreover, if the overall noise-level was still in excess of the legal limit (90 dBA/8 hr. shift in Ontario), it was necessary to pin-point the reasons for this.

Diesel Engine Enclosure Testing

The tests were conducted in CANMET's laboratories (Figs. C-7 to C-10). The engine was mounted in a concrete-bunker and direct coupled to a dynamometer. The reverberations inside this enclosed space increased the noise level readings by 4 to 5 dBA within the frequency range of primary interest, as compared to readings in an open field. However, the usual drill-shack walls will also increase the engine's noise level by several dB. The tests were controlled from an adjoining instrumentation room. Apart from the usual dynamometer read-outs (such as rpm and torque) a number of thermocouples were also mounted, to monitor critical temperatures, including the following: ambient within the bunker, radiator cooling air outlet, diesel-fuel (in tank), hydraulic fluid (in return tank), general air-temperature inside sound-enclosure, exhaust gas temperature and muffler wall temperature. The engine-radiator's coolant temperature-gauge was also carefully monitored.

The general no-load noise level before mounting the enclosure was measured at 90 dBA and 105 dBA at idling and full engine throttle speeds respectively, without any muffler on the engine. On mounting a GM recommended double-wrapped muffler (model 190-9419, type G) these values were reduced to 83 and 102 dBA respectively.

As mentioned, much time was spent in overcoming difficulties encountered with lining up and coupling of the diesel-engine and dynamometer shafts. Consequently, and also because of other urgent commitments, only some 2-1/2 to 3 hrs could be spent on actual noise tests under a range of speed and loading conditions. Even so the following results can already be reported:

a) The engine noise is influenced primarily by the speed at which it is operating. Loading seems to be of secondary, if not negligible, importance (Fig. C-14).

b) Although a torque range from no-load to 300 ft-lb was tested, this was done only in first gear, i.e., at the lowest output-shaft speed (400 rpm); consequently it only represents a range from no-load to some 23 hp. In fourth-gear (2200 rpm output-shaft speed) the maximum loading tested was 90 ft-lb, i.e. some 38 hp. In other words, the engine was not loaded to anywhere near its full capacity of some 90 hp. Consequently, the question of noise levels as a function of higher loading conditions is, as yet, unanswered.

c) The design steps taken to muffle the engine noise were satisfactory on five of the six sides enclosed. Even the special problems posed by the combustion-air intake and combustion-gas outlet, the hydraulic hose passages through the enclosure, and the radiator cooling-air inlet and outlet ductings were satisfactorily overcome. Yet the remaining few percents of opening left around the drive-shaft, engine frame, main skids and throttle control levers let enough sound-energy escape to produce an overall noise-level in excess of the legally specified 90 dBA per 8 hr shift. This fact serves as a powerful reminder of the major difficulties involved in noise-suppression work, and that no opening, no matter how minor, can be left unplugged.

d) The dBA levels recorded in Fig. C-14 were measured at the radiator-air intake point, i.e. on the opposite side to where most of the noise was still escaping. In the operator's position the sound-level readings were some 5 to 7 dBA higher. Even so the noise level at full throttle no-load condition was reduced from the original "as received" value of 105 dBA to 93 dBA (at the air-inlet position), a considerable reduction when remembering that every change of 3 dBA means a halving (or doubling) of the sound-energy level measured.

e) While further design improvements are required on the operator's end of the enclosure to reduce the noise level to within legal limits, monitoring of the diesel-fuel, hydraulic fluid and several air and gas temperatures disclosed another problem as well, namely that the diesel-fuel overheated inside the enclosure. Its temperature rose to 163°F within about an hour of operation. During the same time the bunker ambient air-temperature rose from 52 to 81°F, the air temperature within the sound enclosure from 71 to 139°F, the return hydraulic fluid temperature from 65 to 104°F, the radiator cooling-air outlet temperature from 70 to 124°F, the diesel exhaust gas temperature from 345 to 668°F and the metal surface temperature of the exhaust muffler from 92 to 220°F. The engine radiator coolant temperature remained steady at 180 to 185°F throughout the tests. To overcome the problem with excessive diesel fuel temperatures the tank inside the enclosure was by-passed; a large fuel tank was used instead, located outside of the sound-enclosure. This way fuel temperatures rose from an initial 79°F to only 102°F within some 1-1/2 hours of testing.

f) Apart from the overall sound-level measurements taken at the radiator air-inlet position an octave-band and individual frequency noise level scan was also performed at this location.

Results of the octave-band measurements are shown in Table Cl.

TABLE Cl - Octave-band measurements at engine radiator air-inlet

Octave Band Centre Frequency (Hz)	Noise Level (dB)
31.5	68
63	90
125	94
250	92
500	92
1000	90
2000	85
4000	79
8000	68
16000	58
31500	39

As may be seen the excessive noise-levels are in the frequency range that is most annoying.

Measurements were also taken at the radiator air inlet position, at no-load fully open throttle conditions. The corresponding overall sound level reading was 93-1/2 dBA and 98-1/2 dB.

Silencing of the water-pump unit should then present no great difficulties, either by building a suitable enclosure around it, or by using a factory silenced diesel.

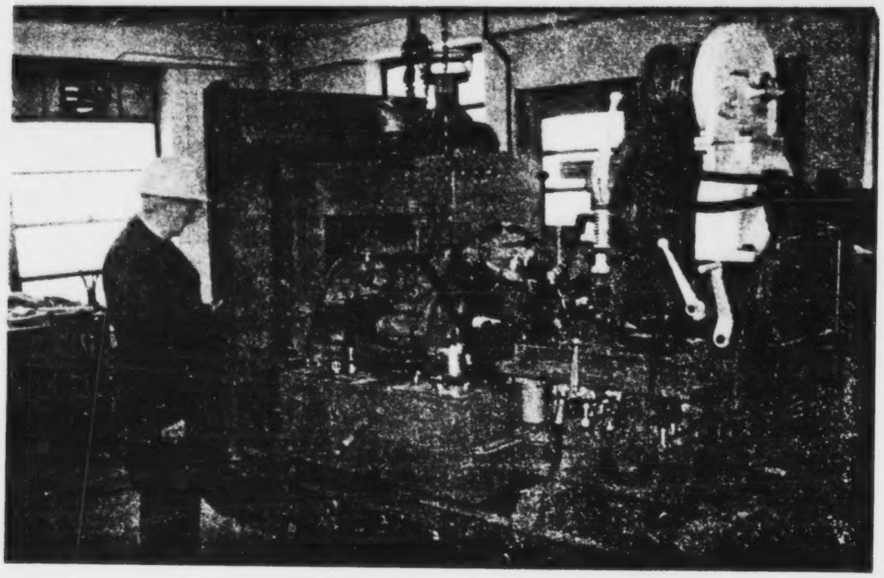


Fig. C-1 - Drill Rig in Early State of Refrofit
Note Stone boat and beginning of cooling-air inlet constructions & fuel and hydraulic oil tanks alongside of engine which were eventually built into enclosure.

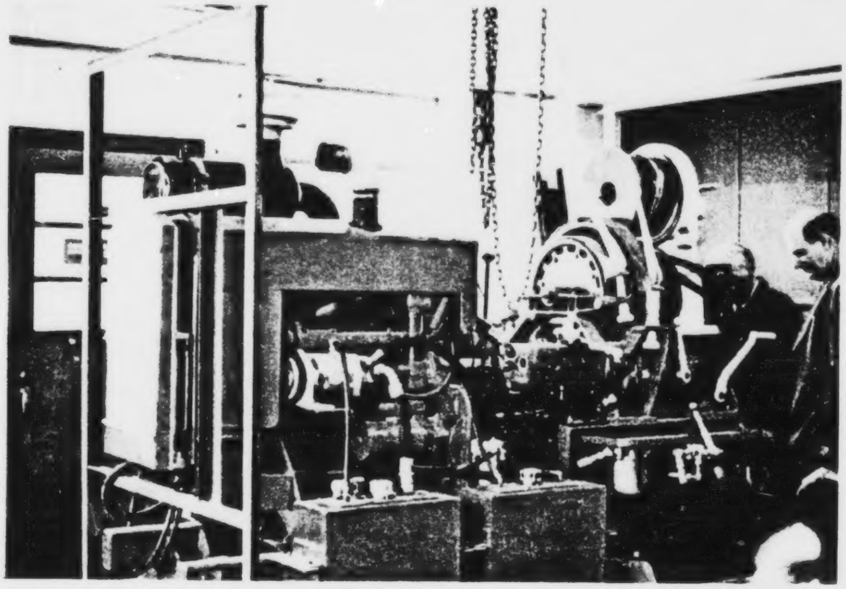


Fig. C-2 - End View of Engine Before Retrofit
Note Combustion air inlet filter & inlet on top of engine (background) and engine exhaust pipe (foreground).

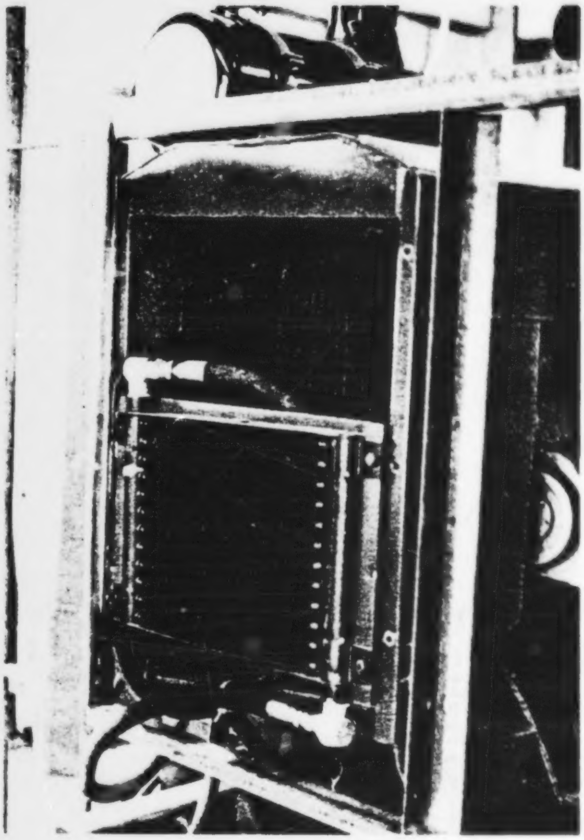


Fig. C-3 - Close-Up of Engine Radiator
Note Hydraulic fluid cooler in front of radiator.

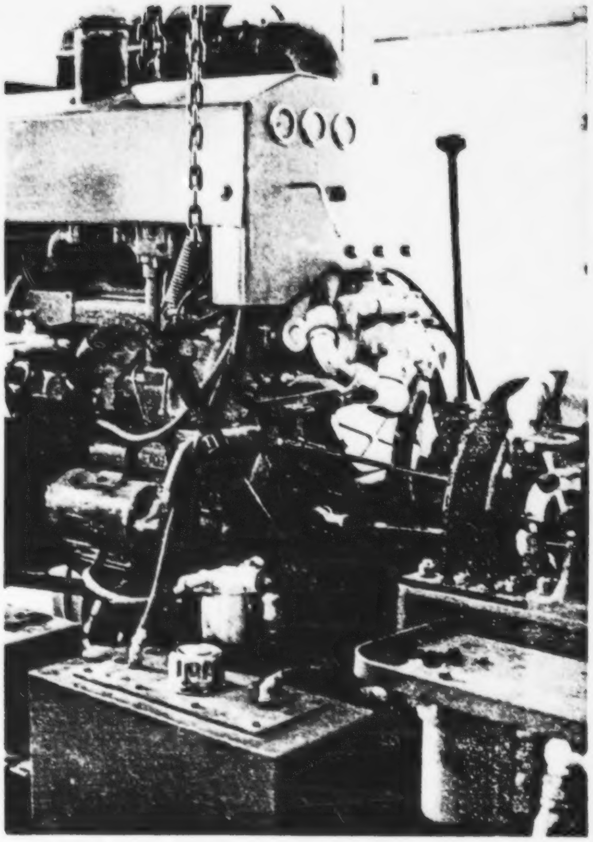


Fig. C-4 - Close-Up of Automotive Transmission Area
Note the complexity of linkages, etc. when considering interfacing with an acoustical enclosure.

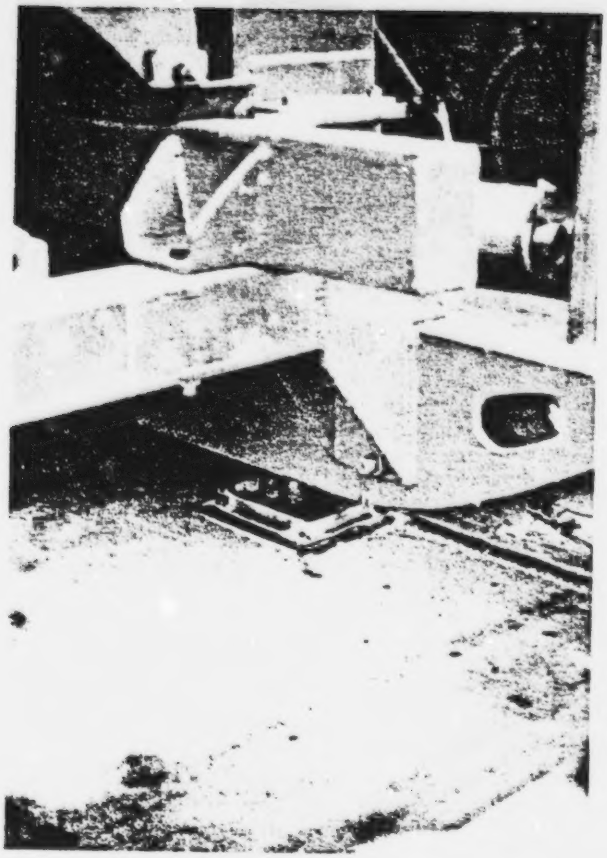


Fig. C-5 - Close-Up of Vibration Isolation Pad Used Between Stone Boat and Original Drill Skid

(subsequently relocated between engine & skid)

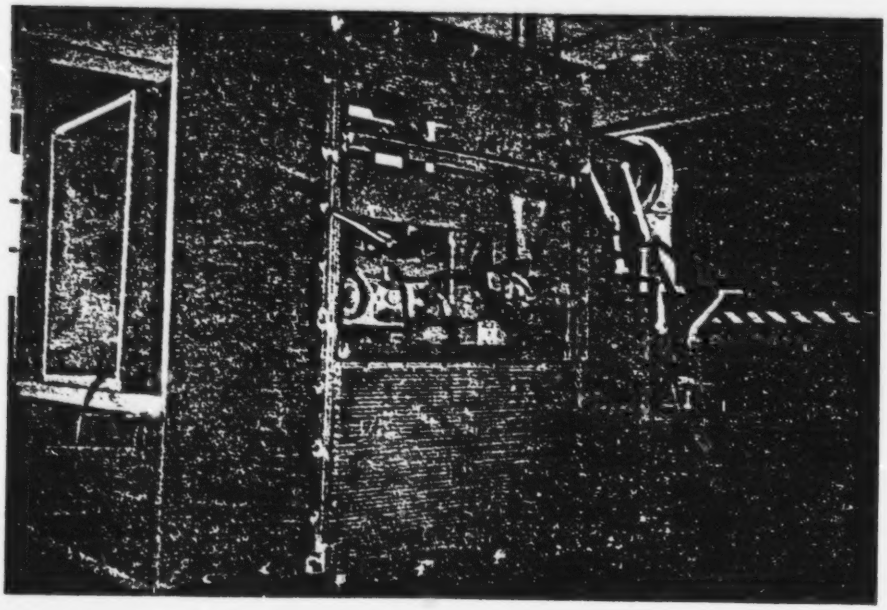


Fig. C-6 - Side Panels and Labyrinth Cooling Air Intake Beginning to Take Shape

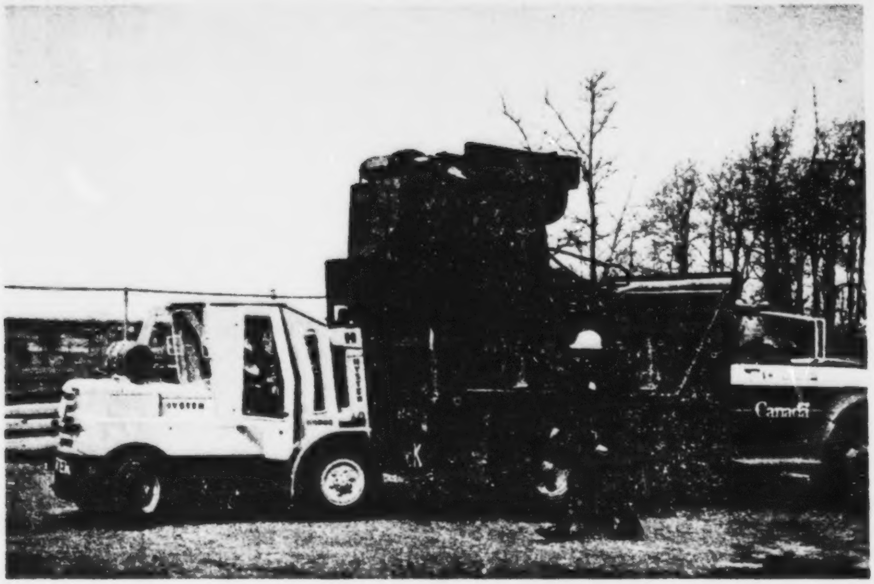


Fig. C-7 - Partially Finished Enclosed Engine Being Delivered to Canmet Dynamometer Test Facilities for Noise vs Load Tests

Fig. C-8 - Enclosed Engine Installed in Dynamometer Test Cell

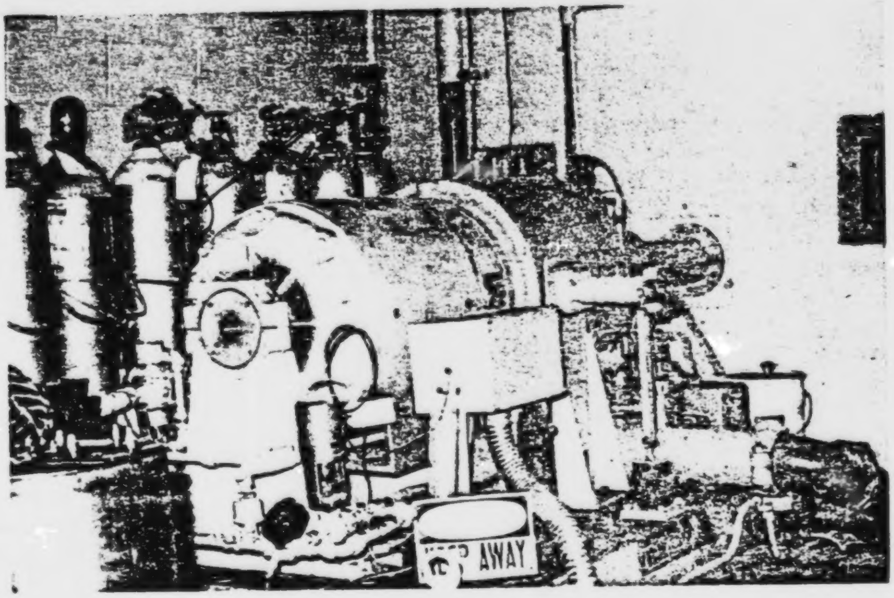


Fig. C-9 - Dynamometer

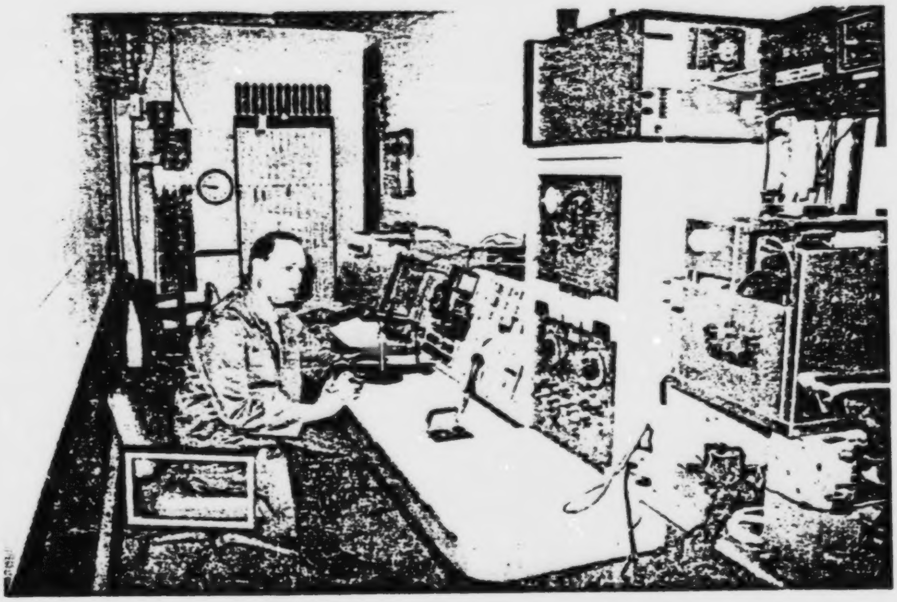


Fig. C-10 - Dynamometer Control Room

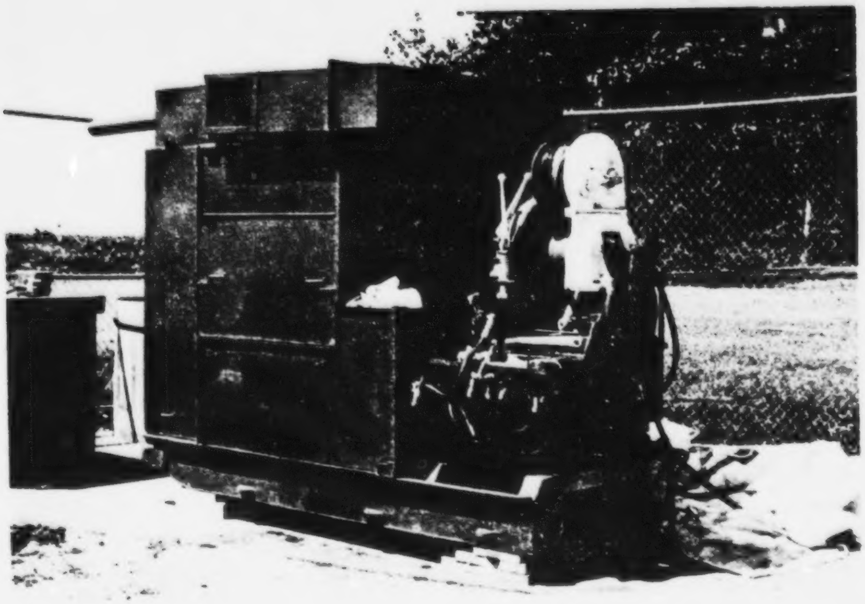


Fig. C-11 - Finished Prototype Enclosure - Frontside View

Note warm air exhaust grill and ducting on top of enclosure (foreground). Exhaust muffler is also enclosed - see rectangular construction to the immediate left of warm air exhaust grill (with exhaust pipe projecting). Note removable inspection panels.

Fig. C-12 - Finished Prototype Enclosure - Backside View

Note removable inspection panel.

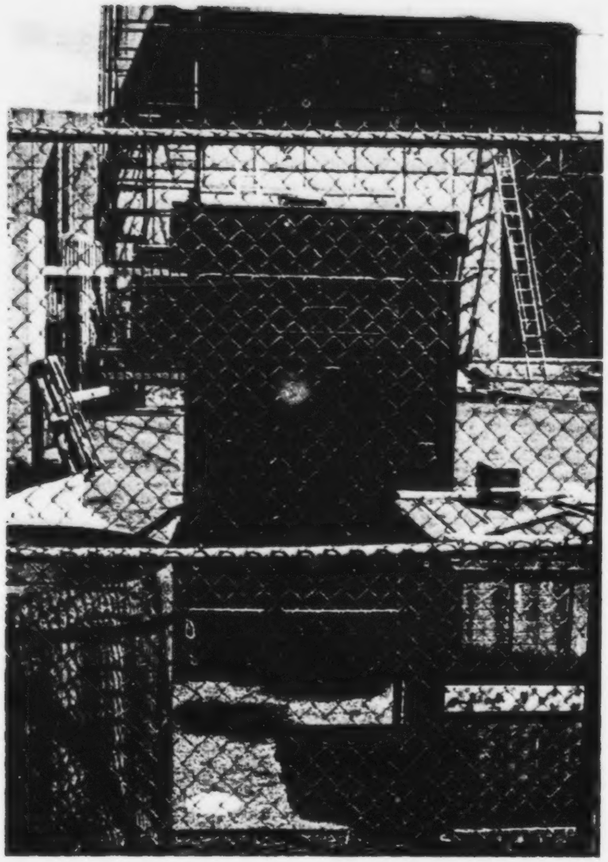


Fig. C-13 - Finished Prototype Enclosure -
End View

Note cooling air inlet grill, removable inspection panel, muffler enclosure and exhaust pipe.

APPENDIX D

CORRESPONDENCE REGARDING PRELIMINARY DESIGN CONCEPTS FOR A CLOSED SWIVEL HEAD

June 1982

Comments re the Proposed Changes for Noise Suppression on Drill Rigs

The idea of helical matched bevel gears would remove most of the noise from this source.

The disadvantages of helical bevel gears are the cost and ratio problems.

You cannot replace this type of gear without a matched replacement. This means a complete tear down of the swivelhead. If either gear becomes damaged and the adjustments on the matched helical gears must be set by dial indicator, a job that the driller might find hard to do.

Most helical bevel gears have a much smaller pinion gear than the crown gear. This would not be possible in diamond drilling as the speed of the drive rod would be too slow.

The configuration on the installation of a pinion the correct ratio size could cause a room problem.

The principle of the hinged slip joint drive would allow you to seal up the crown and pinion drive compartment thereby being able to properly keep lubrication in this area.

One of the major problems with this design is the amount of projection required causing an excessive overhang of the swivelhead. This would lead to excessive vibration and other related drilling problems. This would also make the engineering and fabricating costs very high.

On most drill swivelheads the greatest weakness is the poor supporting design of the drivesleeve bearings. These should be double row ball bearing with a wide supporting area on the drivesleeve. This would also reduce noise and vibration and possibly double the life of the swivelhead components.

Allan Green
Mechanical Superintendent

N. Morrissette
Diamond Drilling Limited

LESLIE T. RUSSELL, Ph.D., P.Eng.
11 Laurentide Drive
Halifax, N.S. B3M 2M9
(902) 443-2169

July 6, 1982.

Mr. R. Cyr, Group Leader,
Noise Abatement Technology
Centre de Reserche Noranda
240 Boulevard Hymus
Point Claire, Quebec
H9R 1G6

Dear Bob,

I received your memo with the comments of Mr. Allen Green and agree with you that the comments are, in general, well considered and constructive. In order to address them properly, I have numbered them and will refer to them one at a time.

1. Mr. Green agrees with our opinion that the use of helical matched bevel gears will remove most of the head noise and, hence, we start on a positive note.

2. At first sight, the disadvantage noted here with regard to cost may really be minor when consideration of replacement costs, down time, etc. are considered. I agree that the cost of the helical matched bevel gears will be higher than the straight bevel gears, but it has yet to be determined by how much. Now the ratio problem: This may indeed be a problem and will depend on what output speed can be delivered from the gear box, if any speed changes can be made within the box and what the necessary drilling speeds are. This can only be addressed at a more involved design stage.

3. I agree with number 3 with the added comment that the helical matched bevel gears may indeed last longer and require less frequent replacement and also I am not certain that replacement by the driller would be that unacceptable.

4. In general, this statement is true, but only detailed design would show if the drive rod speed could be maintained within an acceptable range.

5. Again a detailed design consideration. May or may not be a problem.

6. I agree, as this was the intent. This concept may also be useful with the present gearing in order to maintain proper alignment and tolerances.

7. The extra projection noted here as necessary may cause too large an overhang, but again I am not sure what extra overhang is required at this stage. As Mr. Green states, it may be a problem, but then again it may not be a problem. The comment regarding fabricating costs is, at best, at this stage a guess and I would feel that we must get deeper into the approach before this comment could really be seriously considered.

Cont'd p. 2 ...

8. I certainly agree with this comment regarding bearing types and I note in passing that one or two of the existing shafts within the system are certainly not supported in the best way in this regard.

I am very pleased that we have been able to receive comments like those given by Mr. Green. It appears to me that we are making some definite progress in at least seriously considering possible alternatives.

Yours sincerely,

Leslie T. Russell, Ph.D., P.Eng.

LTR/wr

Vol. 5 Report 8

84-65 M.U. Savich and J.K Weglo

Noise attenuation with exhaust after treatment systems on a scooptram at Falconbridge's Strathcona mine

1984

SYSTÈMES DE POST-ATTÉNUATION DES BRUITS D'ÉCHAPPEMENT D'UNE CHARGEUSE-TRANSPORTEUSE À LA MINE STRATHCONA DE LA FALCONBRIDGE

par

M.U. Savich* et J.K. Weglo**

RÉSUMÉ

La mesure et la détermination du bruit produit par une chargeuse-transporteuse ST4A dans un chantier souterrain dans le cadre d'un cycle de travail simulé et dans trois conditions de systèmes de post-atténuation sont traitées. Ces trois conditions sont :

a) un moteur à découvert,

b) un petit filtre en ligne, comparativement à un filtre plus gros,

c) le filtre plus gros avec un silencieux en ligne, et en série avec un diluteur de fumée.

Les résultats obtenus montrent une atténuation du bruit produit par la chargeuse-transporteuse en opération, de 8 à 15 dBA, à 16 cm du tuyau d'échappement de la machine, à 4,8 dBA près de l'oreille de l'opérateur. Des recommandations sont faites pour atténuer davantage le bruit à l'oreille de l'opérateur en améliorant le diluteur de fumée.

---

* Chercheur scientifique, Laboratoire d'Elliott Lake, CANMET, Energie, Mines et Ressources Canada, Elliott Lake (Ontario).

** Directeur, Protection de l'environnement, Falconbridge Ltée, Falconbridge (Ontario).

NOISE ATTENUATION WITH EXHAUST AFTER TREATMENT SYSTEMS ON A SCOOPTRAM AT FALCONBRIDGE'S STRATHCONA MINE

by

M.U. Savich* and J.K. Weglo**

ABSTRACT

The measurement and evaluation of the noise emanating from an ST4A scooptram in an underground stope under a simulated work cycle, and under three conditions of after-treatment systems is covered.

These were:

a) bare engine,
b) an in-line small filter, compared to a larger filter,
c) the larger filter with an in-line muffler in series with a fume diluter.

The results showed an attenuation of the scooptram at work of 8 to 15 dBA, 16 cm from the exhaust pipe of the machine, to 4.8 dBA at the operator's ear. Recommendations are made to increase the attenuation at the operator's ear by additional improvement in design of the fume diluter.

---

* Research Scientist, Elliot Lake Laboratory, CANMET, Energy, Mines and Resources Canada, Elliot Lake, Ontario.
** Director, Environmental Control, Falconbridge Ltd., Falconbridge, Ontario.

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INTRODUCTION

In current mining operations, the diesel engine provides a safe, efficient and highly mobile source of power. In the major underground mines in Canada the most common types of diesel equipment are Load-Haul-Dump (LHD) machines and ore trucks. In general, there is a tendency to use high horsepower, diesel LHD machines in mines to achieve maximum productivity. The increased use of diesel-powered equipment in underground mines has shown no cause for concern if the engine is adequately maintained.

This research and development of an exhaust filter and fume diluter combination on a ST4A scooptram in an underground stope at the Strathcona Mine was performed to determine the improvement on the working environment of after-treatment systems. Laboratory work had indicated that a reduction of 50 to 80% of particulate matter and more than 90% of hydrocarbons could be expected.

The intent was to capture particulate matter on the filter and allow it to burn off at the normal operating temperature of the engine into less toxic compounds based on measurement by the Ames Test. Since the metal filter was designed with platinum as a catalyst to allow burnoff, at engine temperature it might be expected to oxidize some NO_x to NO_2. The fume diluter was added in series for two reasons. The first was to air quench the engine exhaust to prevent NO_x oxidizing to NO_2. The second was to throw any exhaust fumes away from the operator into the main stope ventilation system. The latter would also provide clear air to the engine to prevent clogging of the filter. Since the filter was in-line on the exhaust, it could also be expected to attenuate noise from this source.

LOAD-HAUL-DUMP MACHINE

A Load-Haul-Dump (LHD) is the noisiest machine in terms of operator noise exposure. Noise sources of LHD machines are (1):

- engine airborne noise from the engine or block structure;
- engine structure-borne noise caused by engine vibrations throughout the machine's structure;
- auxiliary-component noise from the transmission and hydraulic system;
- fan noise;
- exhaust noise;
- air intake noise from the intake and structural radiation from intake piping.

At the component source levels, the highest levels are produced by engine and exhaust outlet noise. Octave band frequency levels were measured on both sides of the motor, and A-weighted sound pressure levels were measured at the exhaust and outlet pipe. Also, while measuring the octave band and A-weighted sound pressure levels, the operator's position was taken into consideration since total machine noise was being measured with a view to its eventual reduction.

Tests were performed at the Strathcona Mine at Stope 23-E2-E4 (Fig. 1). The stope was narrowed by using a plastic curtain, and had a length of 43 m, a width of 15.25 m, and a height of 3 to 5 m. The stope was narrowed to create a regular ventilation current, thus facilitating analyses of gases emitted by the Wagner ST4A scooptram (No. 41). The No. 41 scooptram has a 145 hp engine and has been used for 3,276 hours of operation since it started service on August 22nd, 1979. Because of different absorption characteristics and shapes of walls, noise reflection was not always the same. The test program had two objectives:

1. To determine what noise levels the Wagner ST4A scooptram produced at the

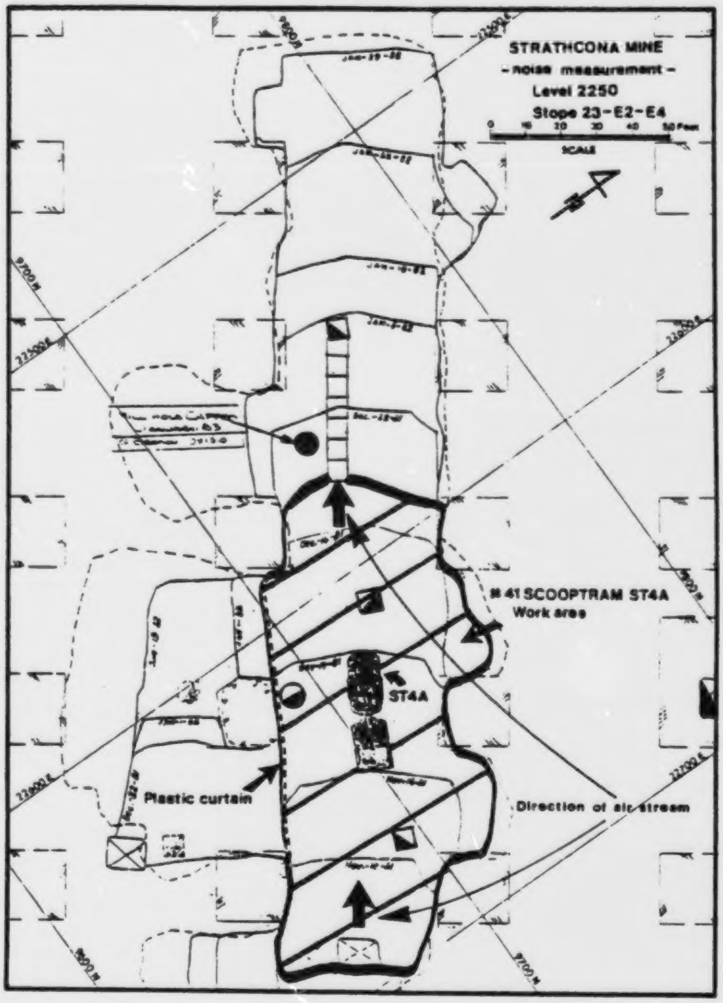

STRATHCONA MINE
- noise measurement -
Level 2250
Stope 23-E2-E4
0 10 20 30 40 50 Feet
SCALE
9700 N
22500 E
22600 E
9600 N
# 41 SCOOPTRAM ST4A
Work area
ST4A
Plastic curtain
Direction of air stream
22700 E

Fig. 1 - The test centre of Wagner ST4A scooptram in the Strathcona Mine.

exhaust outlet, and the levels of operator's exposure to this noise under three conditions (Fig. 2);

- scooptram without muffler or filter;
- scooptram with small and large filter;
- scooptram with filter, muffler and fume diluter.

2. To characterize the noise produced under the three above mentioned conditions and to recommend improvement of, or means for their control.

MEASUREMENT RESULTS

Measurement results are presented in the noise spectrum in octave bands for a distance of 1 m from the left and right sides of the motor and for the operator's ear (Appendix A, 1-4). Also, noise measurements in dBA were performed at the exhaust outlet and operator's ear, and each measurement was then averaged over 1 min (Appendix B, 1-6).

OCTAVE BAND ANALYSIS

Measurements were performed using a Sound Level Meter with conforms with ANSI S1.4-1971 Type 1. Noise measurements in octave bands yielded the following results (Appendix A, 1-4): with the ST4A scooptram, spectrum differences between IDLE and W.O.T. (Wide Open Throttle) noise are well marked. However, an exception occurs at 31.5 Hz. The W.O.T. state of the engine has a high noise level at 125 Hz. The ST4A scooptram has almost equal values between filter 1 and filter 2 on the spectrum, and the results for the two are very similar. In both cases peaks occur at a frequency of 63 Hz. These peaks do not have a marked influence on overall noise in the A-network. In the case of scooptram with filter, muffler and fume diluter two peaks occur: one from the fume diluter at its outlet, and the other at the operator's ear at a frequency of 125 Hz (most probably from the fume diluter inlet, Appendix A, 4).

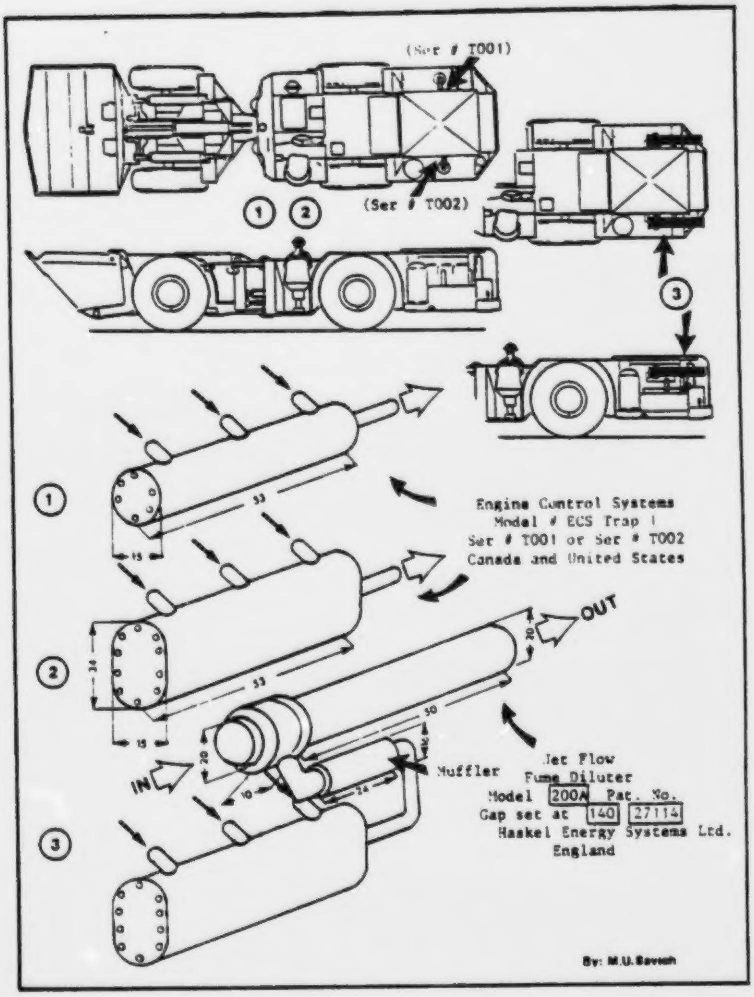

(Ser # T001)
(Ser # T002)
①
②
③
N
53
15
24
20
OUT
30
10
IN
Muffler
Engine Control Systems
Model # ECS Trap 1
Ser # T001 or Ser # T002
Canada and United States
Jet Flow
Fume Diluter
Model 200A Pat. No.
Gap set at 140 27114
Haskel Energy Systems Ltd.
England
By: M.U.Saveh

Fig. 2 - Exhaust treatment during tests:
1) small filter; 2) large filter;
3) filter, muffler and fume diluter.

Neither of these two peaks has a marked influence on the A-network. This noise at the operator's ear can be reduced with deflectors mounted at the diluter's inlet to deflect the noise towards the outlet.

Engine noise at W.O.T. without filter has the highest level of noise, 110.12 dBA for both dides (Table 1). Filter, muffler and fume diluter decrease engine noise by 8 dBA to 102.25 dBA. The exception is the engine with filter 2 alone at its right side. Noise increases at the right hand side are likely because of the heterogenous* metal filter. Despite mounting a muffler and fume diluter, with the engine at idle, noise increases by 3.75 dBA at the operator's ear. This is understandable since the diluter's inlet points directly towards the operator. However, when the engine is at its W.O.T. state, noise is lower by 4.25 dBA. This difference from IDLE to W.O.T. requires further investigation. During this test, impulse, impact and peak noise were also measured. In Table 2 it can be seen that relations are similar to those in Table 1. Left and right sides of the engine both yield the same or similar results.

A-WEIGHTED SOUND PRESSURE LEVEL (SPL_s) MEASUREMENT

A detailed level and time study, using a sample rate of 4/sec averaged over 1 min, may provide enough data to arrive at a statistical distribution or time history graph in the computer, with a very high confidence in results (Appendix C, 1-3). S. Bandopadhyad and R.V. Ramani, in their analysis of diesel exhaust dispersions in underground airways, have adopted the method of averaging over 1 min as being the best one (2). A-weighted sound pressure levels were measured with Type 2 instruments, complying with ANSI S1.4 - 1971.

In this test, exhaust noise at both sides of the motor and total noise at the operator's ear were measured. Using a special attachment the microphone

---

* Metal filters pressed in shop for R & D work and not a normal production run.

Table 1 - Noise levels in A-weighted network of ST4A scooptram under different testing conditions

Condition of Test	Engine Status	Noise in dBA							
		Scooptram (Distance 1 m)						Operator	
		Left Side		Right Side		Both Sides			
		Meas'd	Est'd	Meas'd	Est'd	Meas'd	Est'd	Meas'd	Est'd
Without Filter	Idle	90.75	90.6	91	91.4	90.87	91	83.75	84.2
	W.O.T.	112.25	112.7	108	108.7	110.12	110.7	101.75	101.8
With Filter-1	Idle	88.5	88.9	88.5	88.7	88.5	88.8	81	81.2
	W.O.T.	104.25	104.6	103.25	103.4	103.75	104	96.5	96.1
With Filter-2	Idle	87.5	87.7	88	89	87.75	88.35	82	81.9
	W.O.T.	103.5	104.3	105	105.1	104.25	104.65	97	97.4
With Filter Muffler and Fume Diluter	Idle	86	86.4	87	87.6	86.5	87	87.5	87.2
	W.O.T.	102	102.2	102.5	102.6	102.25	102.4	97.5	97.4

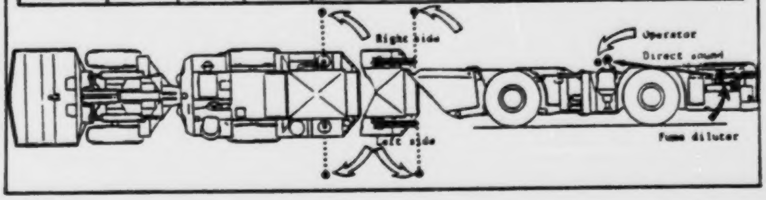
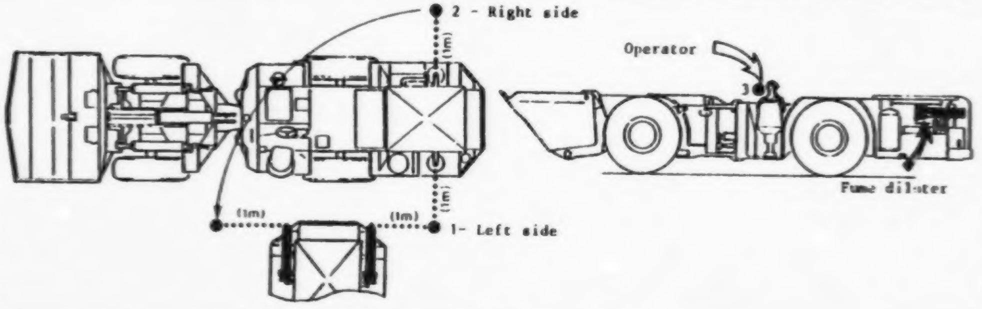


Table 2 - The noise data: impulse, impact hold and peak hold at left and right side, exhaust outlets and the operator's ear during octave band measurement

Engine Status	Position	Level in dB											
		Condition of Test											
		Without Filter			With Filter-1			With Filter-2			With Filter, Muffler and Fume Diluter		
		Impulse	Impact Hold	Peak Hold	Impulse	Impact Hold	Peak Hold	Impulse	Impact Hold	Peak Hold	Impulse	Impact Hold	Peak Hold
Idle	1	92.5	93.5	106.75	89	90.5	103.25	88.5	89.7	102	88	89	101
	2	92	92.5	105.5	89	90.25	103.25	90	91	102.5	87	87.5	100
	3	84.5	86	96.75	81.5	83	94.75	83	88.5	95.5	83	84	96
W.O.T.	1	112.25	113	124.5	104.5	105.5	117	104	104.5	117	103.5	103.5	115
	2	108.75	109.75	121.5	103.5	104.5	116.25	105.5	106	118.5	103	103	115.5
	3	102	102.5	114.5	96.5	97.5	105.25	97.5	98	109.5	97.5	98	109.5



was mounted 16 cm behind the pipe of the exhaust outlet. The microphone was covered with a windscreen to protect it from emitted gases and impurities. IDLE and W.O.T. noise was measured while the ST4A scooptram remained stationary, and also under simulated working conditions (L.H.D.). IDLE and W.O.T. measurements were carried out simultaneously with the octave band analysis which has already been discussed.

Measured results are displayed in Appendix B, 1-6). To improve absolute and relative values at the exhaust outlet all results were obtained by using the same instruments (Logger type = dB-301/16). When measuring noise at the operator's ear, different instruments were used (Logger type = dB-301/16). All instruments were calibrated before and after completing the measurements. To characterize noise, 1 min averaging levels were deployed, and the following engine states were evaluated: IDLE, W.O.T. and working condition. In Appendix B, 1-6, the mean and standard deviation were calculated for each motor state. Results are sorted in Table 3. From these results it is clear that the ST4A scooptram with filter, muffler and fume diluter provides the best attenuation on both exhaust pipes. On the left side the attenuation is from 11.3 dBA to 15.3 dBA. At the operator's ear, attenuation is a lot less, from 1.9 dBA to 4.8 dBA. The fume diluter produces noise from 1.7 to 1.6 dBA more than when only filter 2 is installed. While the motor is in its work state, the noise level is the same as with filter 2. The resulting confidence was evaluated using a t-distribution test. In Table 4 there are calculated value lengths of a 99% confidence interval in dBA. In only three cases is the length of the confidence interval longer. Two of the cases occur when filter 2 is on the right side of the motor at W.O.T.; and one at the operator's ear at IDLE. Perhaps this is because the duration of observations were shorter, or due to the operator moving his head. The third case is when the motor is equipped

Table 3 - A-weighted sound pressure levels (SPL_s) of the Wagner ST4A scooptram at left and right side, exhaust outlets and the operator's ear. Engine at IDLE, W.O.T. and Work states.

Condition of Test	Engine Status	Minutes	Noise in dBA							
			Scooptram						Operator (3)	
			Left Side (1)		Right Side (2)		Both Sides			
			Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Without Filter	Idle	33	102.76	0.61	101.86	0.86	101.91	1.13	86.24	1.25
	W.O.T.	28	119.93	1.46	116.93	1.7	118.43	2.26	102.64	1.7[illegible]
	Work	31	116.58	1.18	112.29	1.04	114.44	2.43	100.94	1.18
With Filter-1	Idle	27	97.22	0.97	97.93	1.21	97.57	1.14	84.7	2.46
	W.O.T.	26	108.69	0.97	109.04	1.7	108.87	1.4	96.92	1.52
	Work	32	105.63	1.18	103.91	1.04	104.77	1.51	97.41	1.1
With Filter-2	Idle	14	97	-	96.64	0.5	96.82	0.39	82.64	2.71
	W.O.T.	11	109.91	0.83	110.09	1.64	110	1.27	95.18	0.4
	Work	28	106.54	1.14	104.43	1.62	105.46	1.75	96.14	0.36
With Filter Muffler and Fume Diluter	Idle	13	91.46	0.52	95	-	93.23	1.84	84.31	0.48
	W.O.T.	12	106.67	0.49	108	0.74	107.33	0.92	96.75	0.45
	Work	30	101.3	1.09	104.17	0.91	102.75	1.96	96.13	0.86

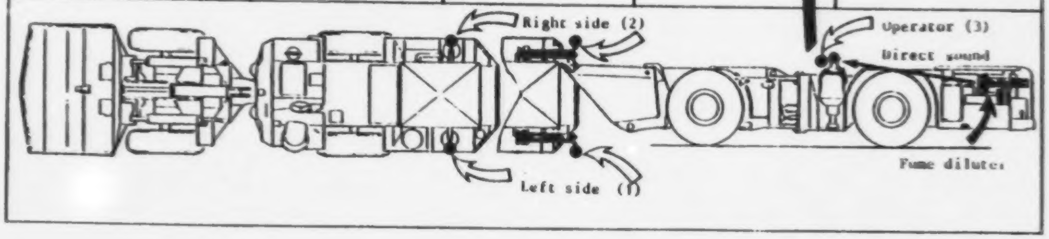
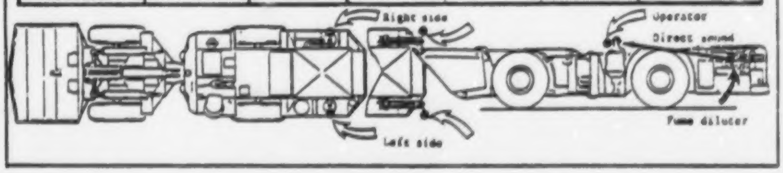


Table 4 - Results of the t-distribution test.

Condition of Test	Engine Status	Minutes	Length of 99% confidence interval in dBA			
			Scooptram			Operator
			Left Side	Right Side	Both Sides	
Without Filter	Idle	33	0.54	0.78	1.02	1.12
	W.O.T.	28	1.52	1.78	2.36	1.8
	Work	31	1.1	0.96	2.25	1.1
With Filter-1	Idle	21	1.04	1.3	1.22	2.6
	W.O.T.	26	1.06	1.86	1.53	1.65
	Work	32	1.08	0.95	1.37	1.0
With Filter-2	Idle	14	-	0.84	0.63	4.36
	W.O.T.	11	1.5	3.13	1.21	0.76
	Work	28	1.2	1.7	1.83	0.22
With Filter Muffler and Fume Diluter	Idle	13	0.88	-	3.12	0.26
	W.O.T.	12	0.88	1.3	1.65	0.8
	Work	30	1.1	0.92	1.97	0.32


Right side
Left side
Operator
Direct sound
Fume diluter

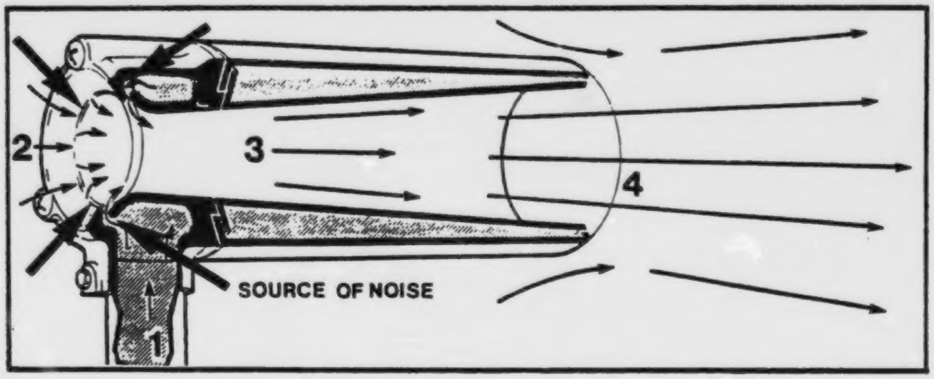
with filter, muffler and fume diluter on both sides of the scooptram. It has a confidence interval slightly greater than 3 dBA, which can be explained by uneven metal filling of filters or the small dimensions of resonant mufflers.

The range of tolerance limits for a Type 2 Sound Level Meter is from plus 3.5 dB or minus 4.0 dB in the low frequencies, to plus or minus 6.5 dBA at 8000 Hz. Sound level tolerance limits are widest at 4000 to 8000 Hz, and the noise level reading is greatly influenced by these limits, especially at the higher frequencies. In light of the foregoing, an arbitrary decision was made to use a ± 2 dBA limit on overall noise dosimeter accuracy (3). This gives another reason for a high degree of confidence in all the results presented in Table 3 and tested in Table 4. All lengths of 99% confidence intervals in dBA are under 4 dBA, except where there is 4.36 dBA at the operator's ear.

NOISE PROBLEMS OF FUME DILUTER

Completed analyses clearly show that the fume filter increases noise at the operator's seat. The source of noise is a radial connection which is released through the annular gap to accelerate over the aerofoil surface (Fig. 3). Marked increases of noise occur at 1000 Hz and 2000 Hz (Appendix A, 4). Lower frequencies have no effect in increasing noise. This is proof that noise at the operator's seat can be decreased by using a saucer-shaped deflector, with its concave surface pointed at the throat of the tube (Fig. 4).

Ideal reflector size and its distance from the throat of the fume diluter can be ascertained only through further experiments. Installed ECS resonant mufflers should be further tested without fume diluters, as should fume diluters without the resonant mufflers. Should this demonstrate that the muffler is inefficient in tandem with the filter and fume diluter, more


2
3
4
1
SOURCE OF NOISE

1. Primary supply enters; 3. Induced air mixes;
2. Secondary supply; 4. High velocity air emitted.

Fig. 3 - Fume diluter (4).

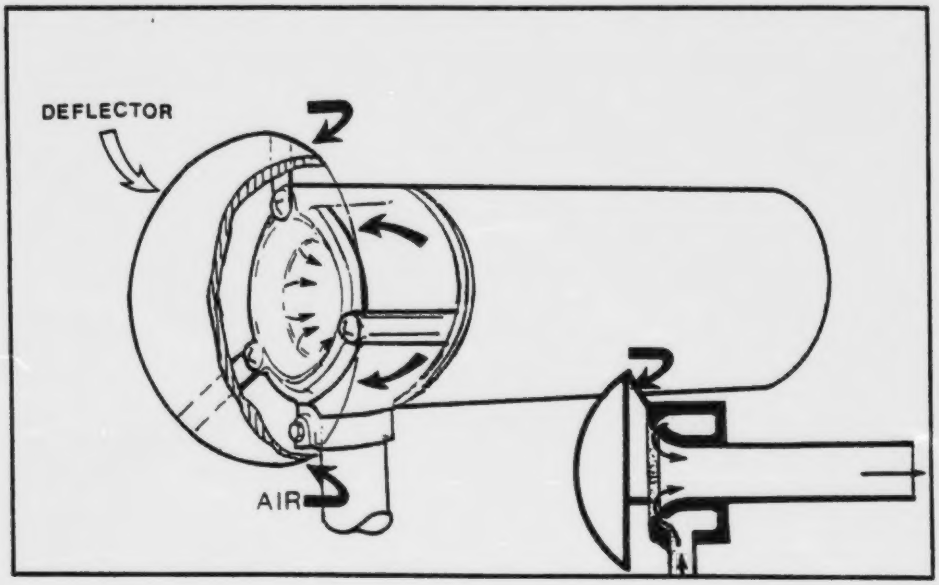

DEFLECTOR
AIR

Fig. 4 - Deflector in fume diluter.

attention will have to be given to the fume diluter. Modifying the fume diluter and deploying it in tandem with the resonant muffler could make a good technical solution. Close approximations of the design chart have shown that new attempts can be made at decreasing noise in this system. Experimental work, using the design chart for lined duct or resonant mufflers will greatly reduce the theoretical work required for improved design (5).

CONCLUSION

This is the first study which concentrates exclusively on the noise of Load-Haul-Dump (LHD) vehicles emitted at the exhaust outlet under different engine states in relation to the operator's site. The study had two objectives:

1. to determine what noise levels the Wagner ST4A scooptram produces at the exhaust outlet and the levels of operator's exposure to this noise under four conditions:
   - scooptram without muffler or filter;
   - scooptram with small filter;
   - scooptram with large filter;
   - scooptram with large filter, muffler and fume diluter.
2. To recommend improvements or means for their control.

Measurement results demonstrate that the combination of filter, muffler and fume diluter provides maximum abatement of exhaust noise - around 8 dBA - for both sides of the outlet. The operator is exposed to a higher level of noise when a fume diluter is built into the entire system. This is understandable, since the fume diluter is a new source of noise, noise which must be decreased. Studying this problem is fairly complex and demands lengthy experimentation. As a provisional measure a saucer-shaped deflector is recommended. This deflector must be mounted at the inlet of the fume diluter to protect the operator from the noise. After this experimental confirmation, this method is recommended for practical and permanent utilization.

These results and their evaluation show that:

1. The use of filters alone can reduce the noise level at the operator's ear at W.O.T. to within 5 dBA of the noise standard.
2. Fume diluters add noise because of their design and this noise can be reduced with further evaluation and initially with a noise deflector.
3. Noise, one meter from the scooptram, is reduced by 11.7 dBA from exhaust treatment alone, and will reduce the noise hazard for other personnel in the stope.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of R. Van Ooteghen of the Mines Accident Prevention Association of Ontario for taking measurements.

The support of Falconbridge Ltd. through D. Cornett, Mine Superintendent, S. Schultz, Ventilation Engineer, J. Calvert, Master Mechanic, and D. McPhee, Occupational Health Technician is also acknowledged.

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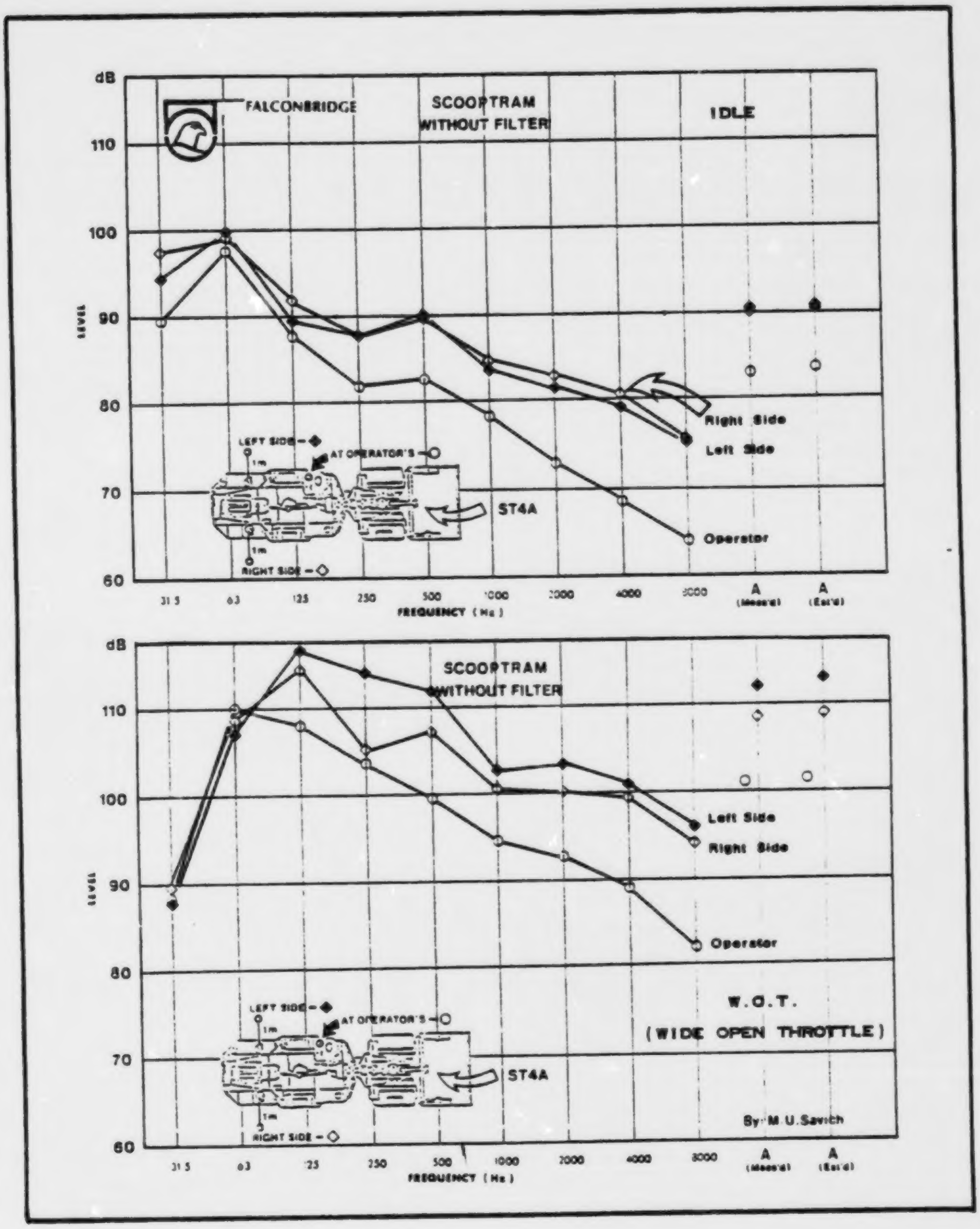
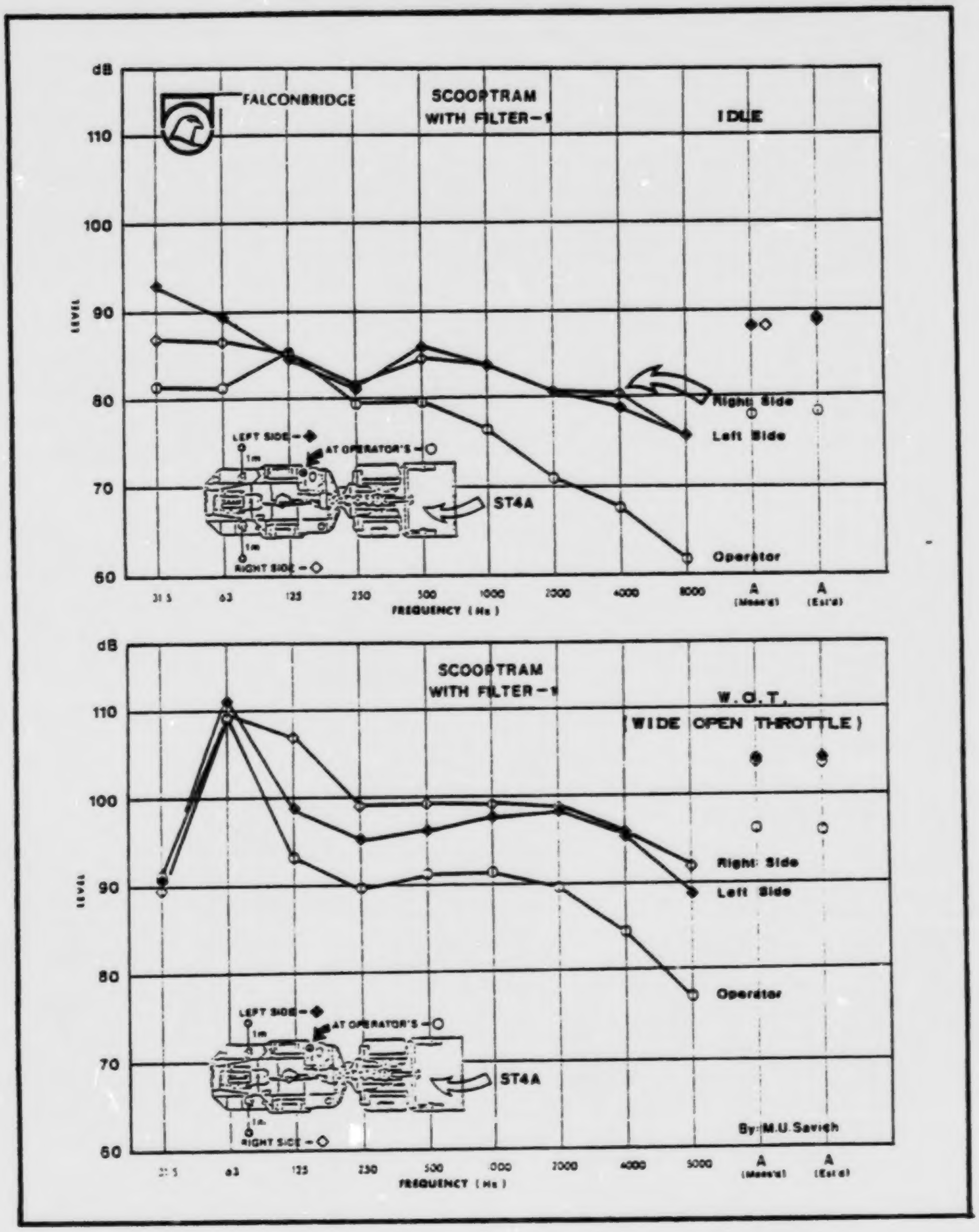
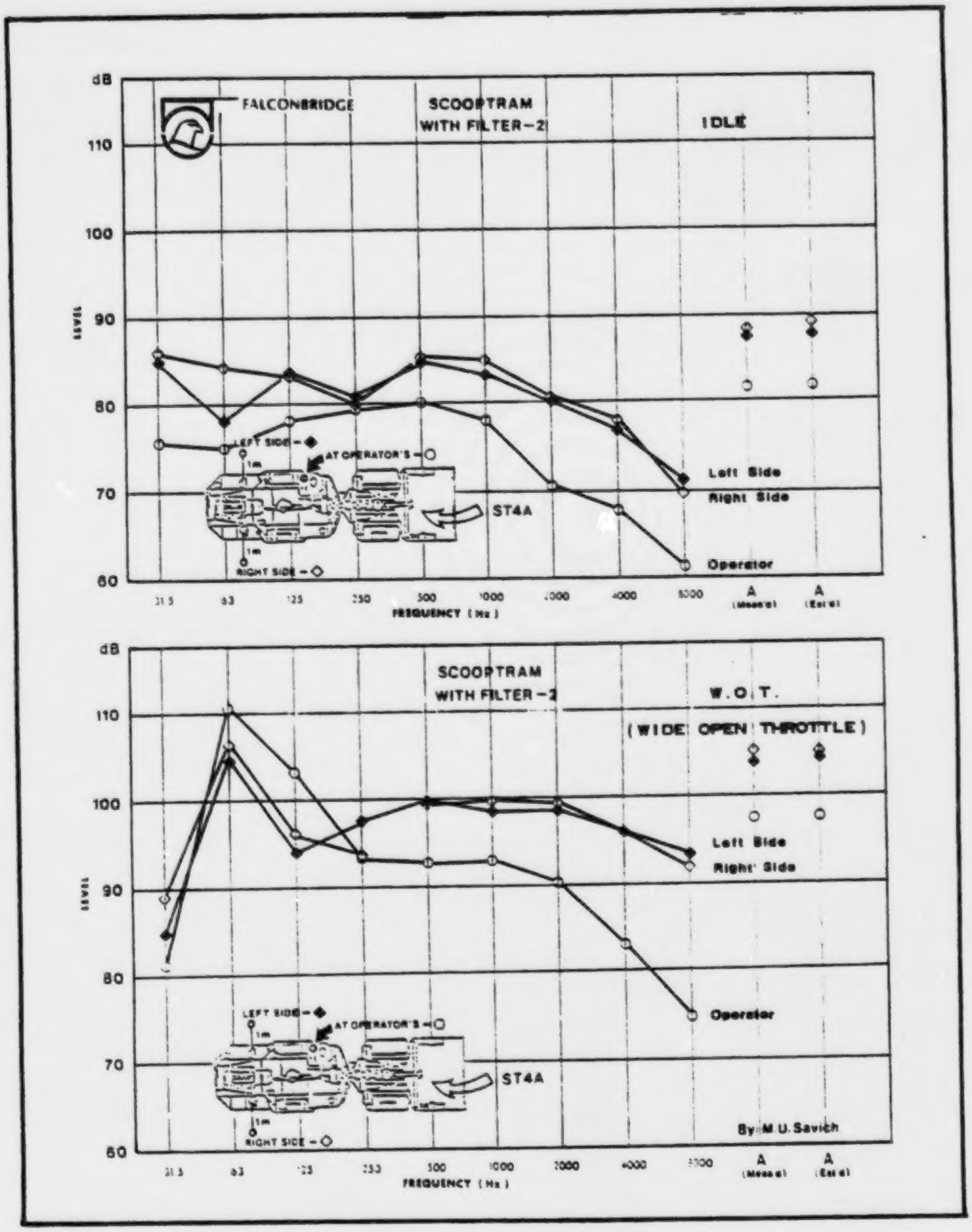


The noise spectrum in octave bands, produced by the ST4A scooptram without filter at engine states IDLE and W.O.T.

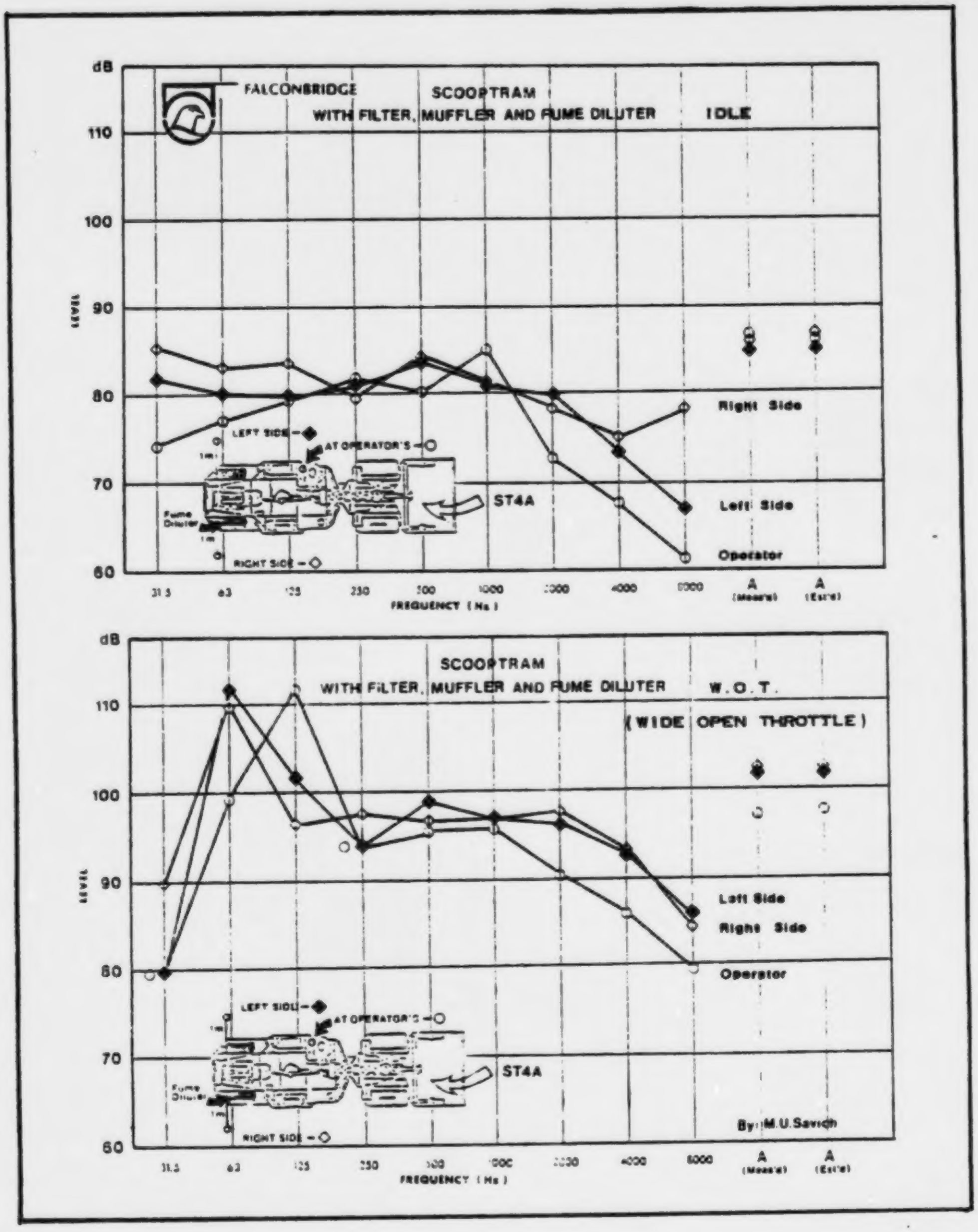


The noise spectrum in octave bands, produced by the ST4A scooptram with filter 1 at engine states IDLE and W.O.T.

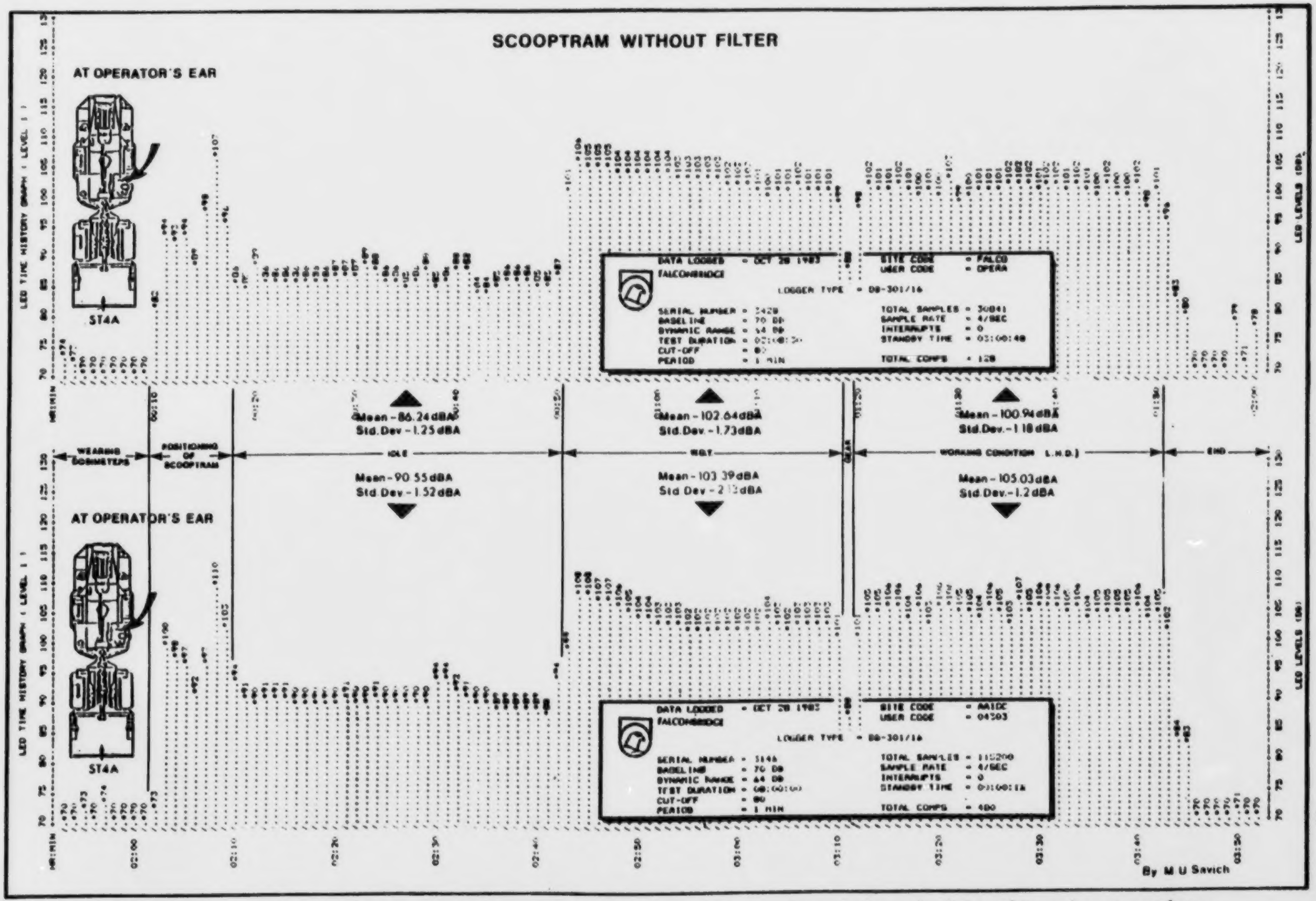


The noise spectrum in octave bands, produced by the ST4A scooptram with filter 2 at engine states IDLE and W.O.T.

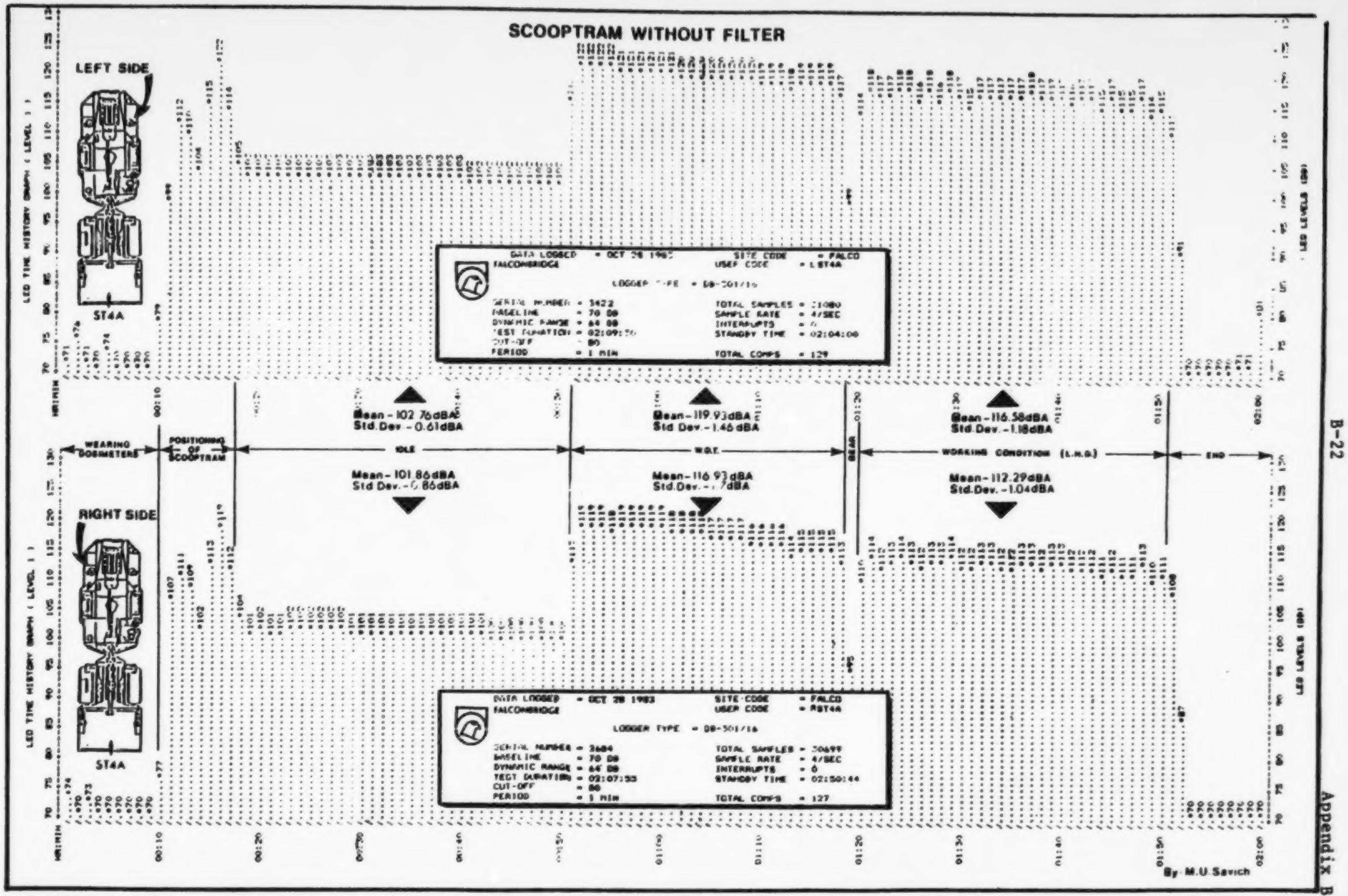
Appendix A-4



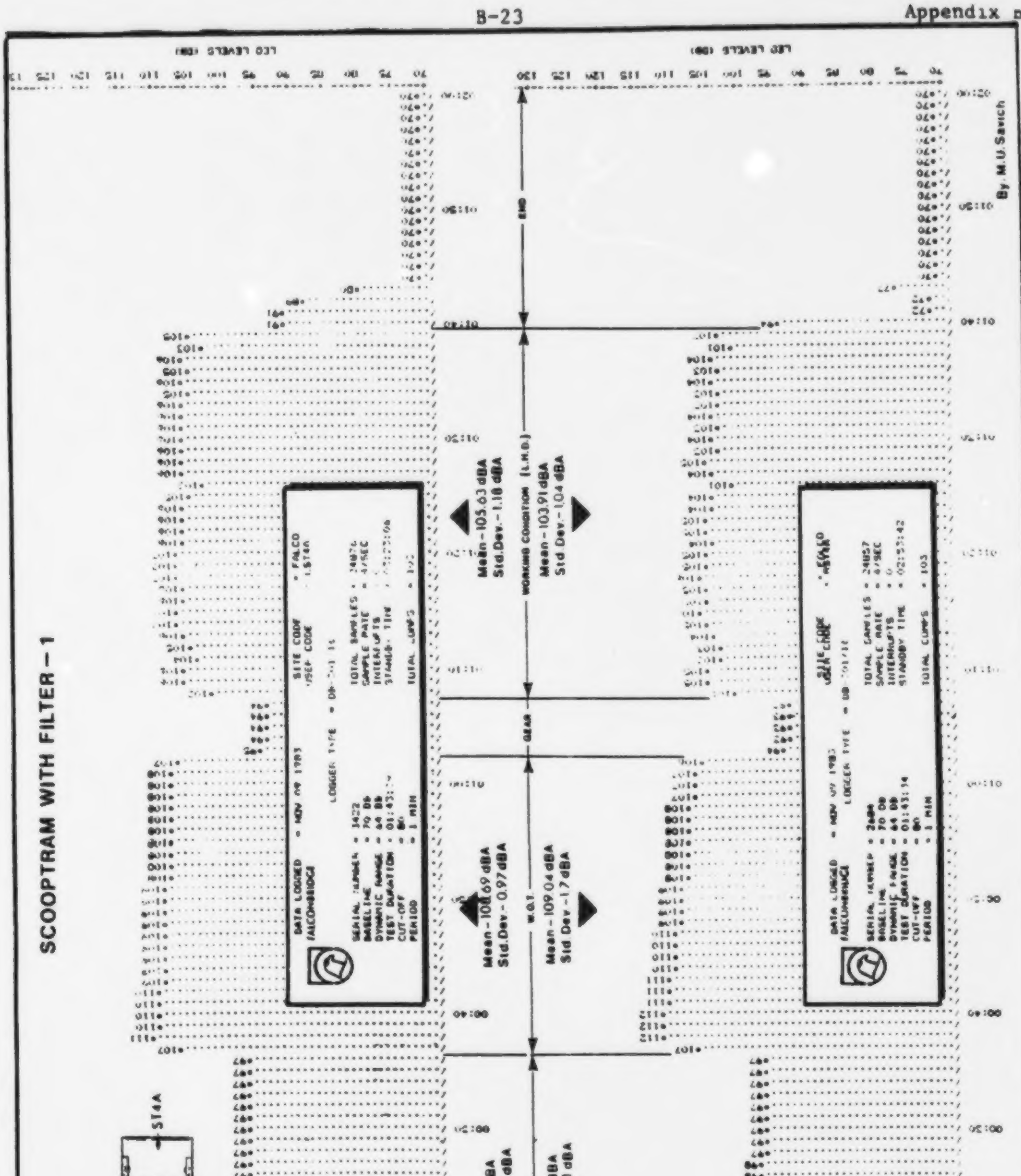
The noise spectrum in octave bands, produced by the ST4A scooptram with filter, muffler and fume diluter at engine states IDLE and W.O.T.



Noise measurements in dBA, of the ST4A scooptram without filter, from left and right side exhaust outlets.

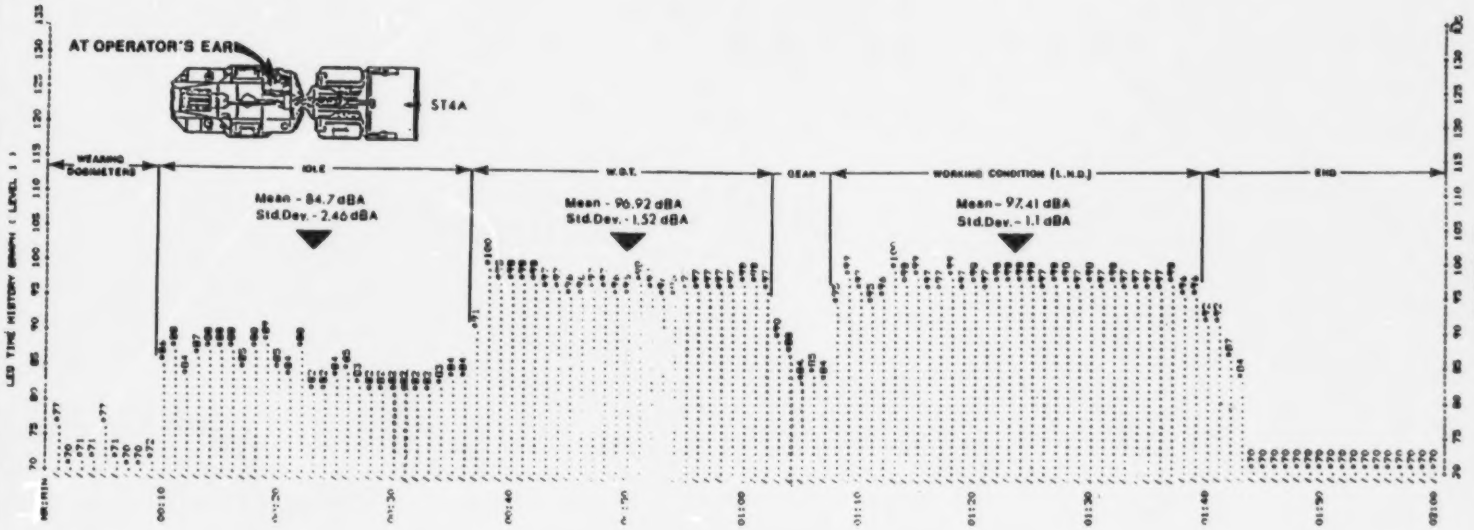


Noise measurements, in dBA, of the ST4A scooptram at operator's ear. These measurements were made using two dosimeters.



Noise measurements, in dBA, of the ST4A scooptram, from left and right side exhaust outlets.

SCOOPTRAM WITH FILTER — 1



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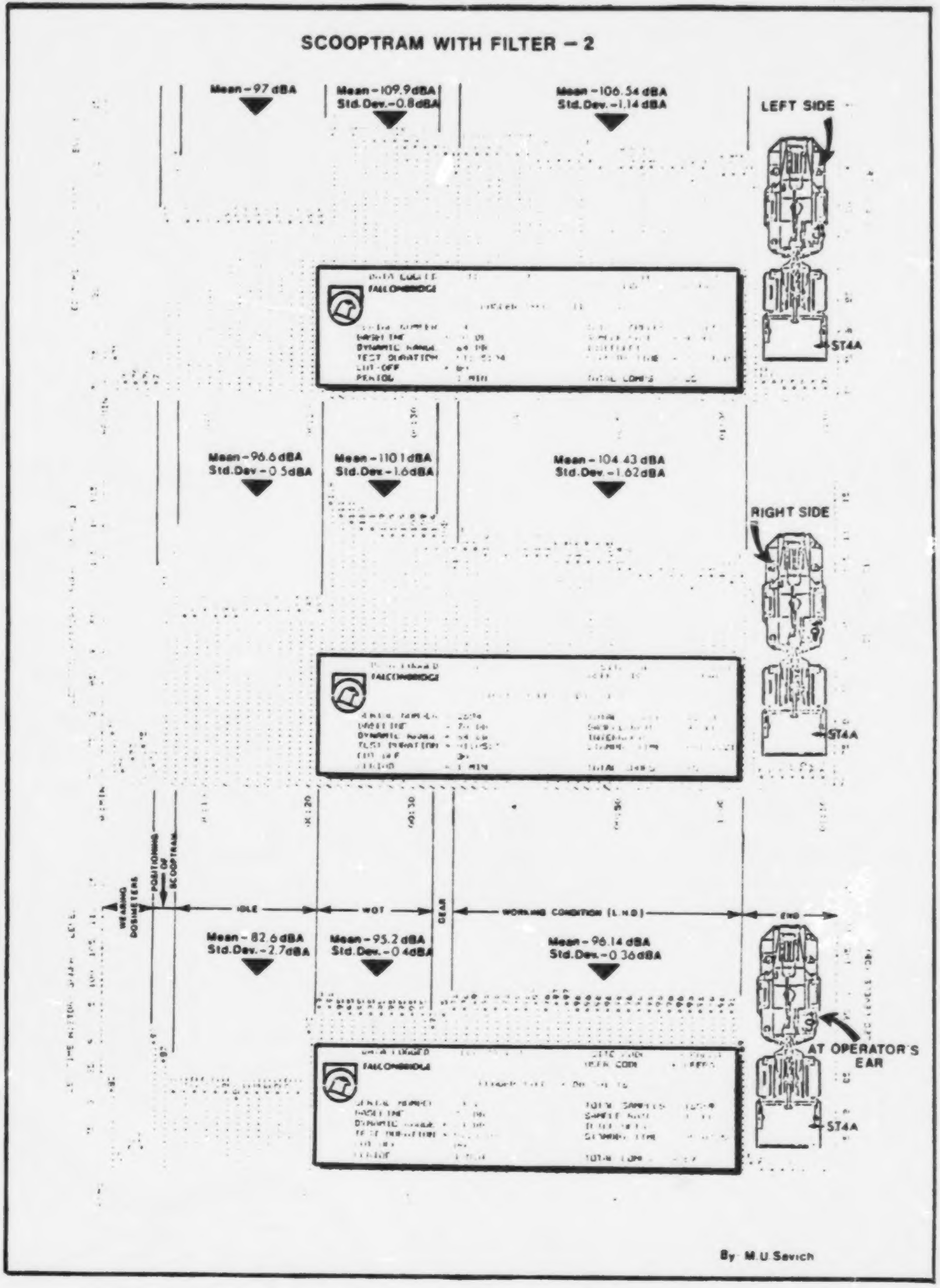
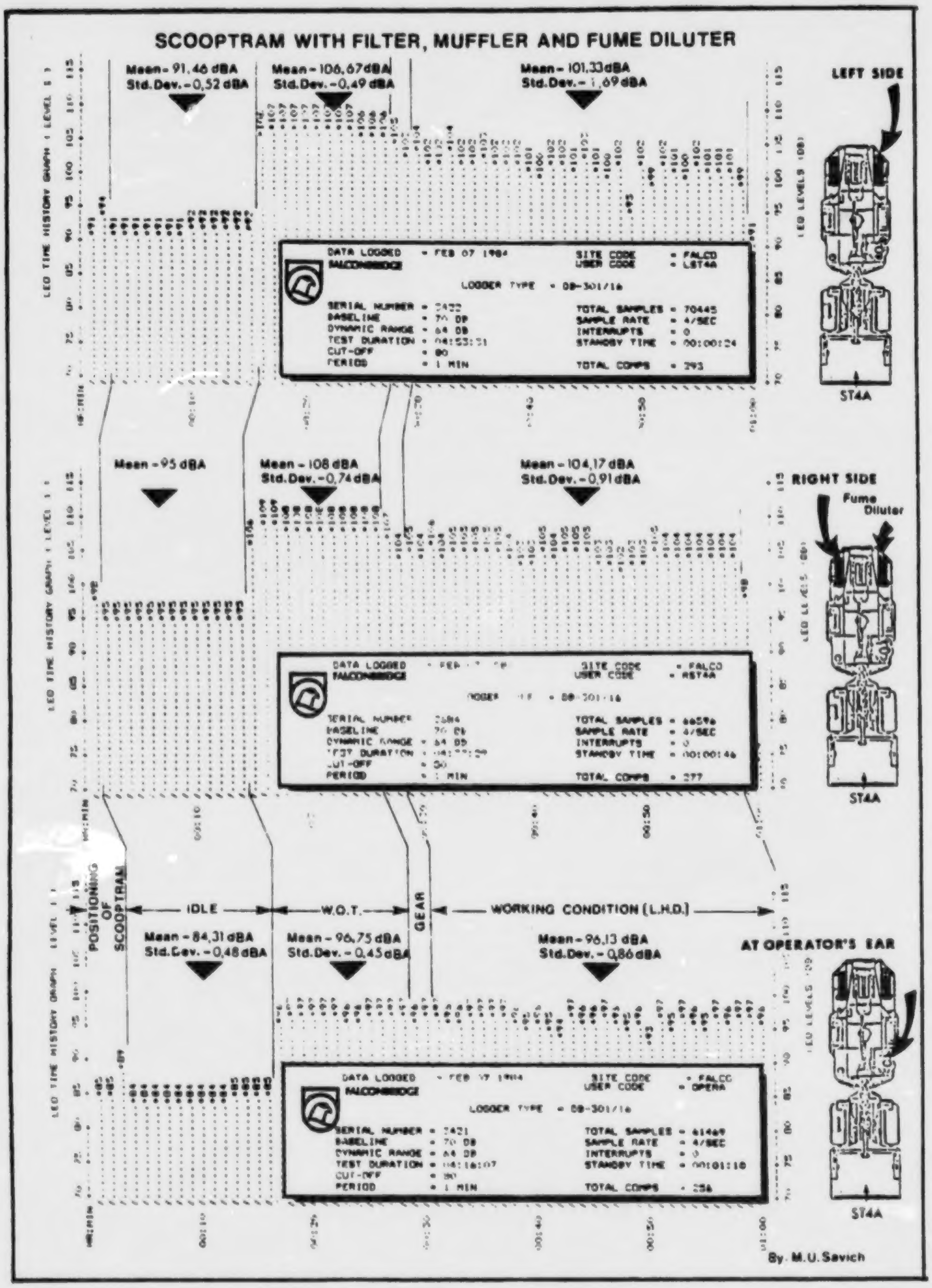
Noise measurements, in dBA, of the ST4A scooptram at the operator's ear.

By M.U. Savich



Noise measurements, in dBA, of the ST4A scooptram with filter 2 from left and right side exhaust outlets, and at the operator's ear.



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CUT-OFF          = 80
PERIOD           = 1 MIN                TOTAL COMPS    = 277
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TEST DURATION    = 04:16:07             STANDBY TIME   = 00:01:10
CUT-OFF          = 80
PERIOD           = 1 MIN                TOTAL COMPS    = 256
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Noise measurements, in dBA, of the ST4A scooptram with filter, muffler and fume diluter from left and right side exhaust outlets, and at the operator's ear.

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VOL. 5 Report 9

84-69 M.U. Savich and J.K. Weglo

Practical work on the noise attenuation with exhaust after treatment systems on a ST4A scooptram in Strathcona mine, Falconbridge Ltd.

1984

PRACTICAL WORK ON THE NOISE ATTENUATION WITH EXHAUST AFTER TREATMENT SYSTEMS ON A ST4A SCOOPTRAM IN STRATHCONA MINE, FALCONBRIDGE LTD.

by

M.U. Savich* and J.K. Weglo**

ABSTRACT

The measurement and evaluation of the noise emanating from a ST4A scooptram in an underground stope under a simulated work cycle, and under three conditions of after treatment systems is covered:

These were:

a) bare engine,

b) an in-line small filter compared to a larger filter,

c) the larger filter with an in-line muffler in series with a fume diluter.

The results showed an attenuation of the scooptram at work of 8 to 15 dBA, 16 cm from the exhaust pipe of the machine, to 4.8 dBA at the operator's ear. Recommendations are made to increase the attenuation at the operator's ear by additional improvement in design of the fume diluter.

---

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** Director, Environmental Control, Falconbridge Ltd., Falconbridge, Ontario.

TRAVAUX PRATIQUES SUR LES SYSTÈMES DE POST-ATTÉNUATION DES BRUITS D'ÉCHAPPEMENT D'UNE CHARGEUSE-TRANSPORTEUSE ST4A À LA MINE STRATHCONA DE LA FALCONBRIDGE LTÉE

par

M.U. Savich* et J.K. Weglo**

RÉSUMÉ

La mesure et la détermination du bruit produit par une chargeuse-transporteuse ST4A dans un chantier souterrain dans le cadre d'un travail simulé et dans trois conditions de systèmes de post-atténuation sont traitées. Ces trois conditions sont :

a) un moteur à découvert,
b) un petit filtre en ligne, comparativement à un filtre plus gros,
c) le filtre plus gros avec un silencieux en ligne, et en série avec un diluteur de fumée.

Les résultats obtenus montrent une atténuation du bruit produit par la chargeuse-transporteuse en opération, de 8 à 15 dBA, à 16 cm du tuyau d'échappement de la machine, à 4,8 dBA près de l'oreille de l'opérateur. Des recommandations sont faites pour atténuer davantage le bruit à l'oreille de l'opérateur en améliorant le diluteur de fumée.

---

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INTRODUCTION

In current mining operations the diesel engine provides a safe, efficient, and highly mobile source of power. In the major underground mines in Canada the most common types of diesel equipment are load-haul-dump (LHD) machines and ore trucks. In general, there is a tendency to use high-horsepower diesel LHD machines in mines to achieve maximum productivity. The increased use of diesel powered equipmnet in underground mines has not shown any cause for concern if the engine is adequately maintained.

This research and development of an exhaust filter and fume diluter combination on a ST4A scooptram in an underground stope at the Strathcona Mine was performed to determine the improvement on the working environment of after treatment systems. Laboratory work had indicated that a reduction of 50 to 80% of particulate matter and more than 90% of hydrocarbons could be expected.

The intent was to capture particulate matter on the filter and allow it to burn off at the normal operating temperature of the engine into less toxic compounds based on measurement by the Ames Test. Since the metal filter was designed with platinum as a catalyst to allow burnoff at engine temperature it might be expected to oxidize some NO_x to NO_2. The fume diluter was added in series for two reasons. The first was to air-quench the engine exhaust to prevent NO_x oxidizing to NO_2. The second was to throw any exhaust fumes away from the operator into the main stope ventilation system. The latter would also provide clean air to the engine to prevent clogging of the filter.

Since the filter was in-line on the exhaust, it could also be expected to attenuate noise from this source. This report presents the measurement of the noise and evaluation of these results.

LOAD-HAUL-DUMP MACHINE

A load-haul-dump (LHD) is the noisiest machine in terms of operator noise exposure. Noise sources of LHD machines are (1):

- engine airborne noise from the engine or block structure;
- engine structure-borne noise caused by engine vibrations throughout the machine's structure;
- auxiliary-component noise from the transmission and hydraulic system;
- fan noise;
- exhaust noise;
- air intake noise from the intake and structural radiation from intake piping.

At the component source levels, the highest levels are produced by engine and exhaust outlet noise. Levels of these two sources were measured. Octave band frequency levels were measured on both sides of the motor, and A-weighted sound pressure levels were measured at the exhaust and outlet pipe. Also, while measuring the octave band and A-weighted sound pressure levels, the operator's position was taken into consideration since total machine noise was being measured with a view to its eventual reduction.

Tests were performed in the Strathcona Mine at Stope 23-E2-E4 (Fig. 1). The stope was narrowed by using a plastic curtain which had a length of 43 m (140 ft), a width of 15.25 m (50 ft), and a height of 3 to 5 m (10 to 16.5 ft). The stope was narrowed to create a regular ventilation current, thus facilitating analyses of gases emitted by the Wagner ST4A Scooptram (No. 41). The No. 41 scooptram has a 145 hp engine and had been used for 3,276 hours of operation since it started service on August 22nd, 1979. Because of different absorption characteristics and shapes of walls, noise reflection was not always the same. The test program had two objectives:

1. To determine what noise levels the Wagner ST4A scooptram produced at the

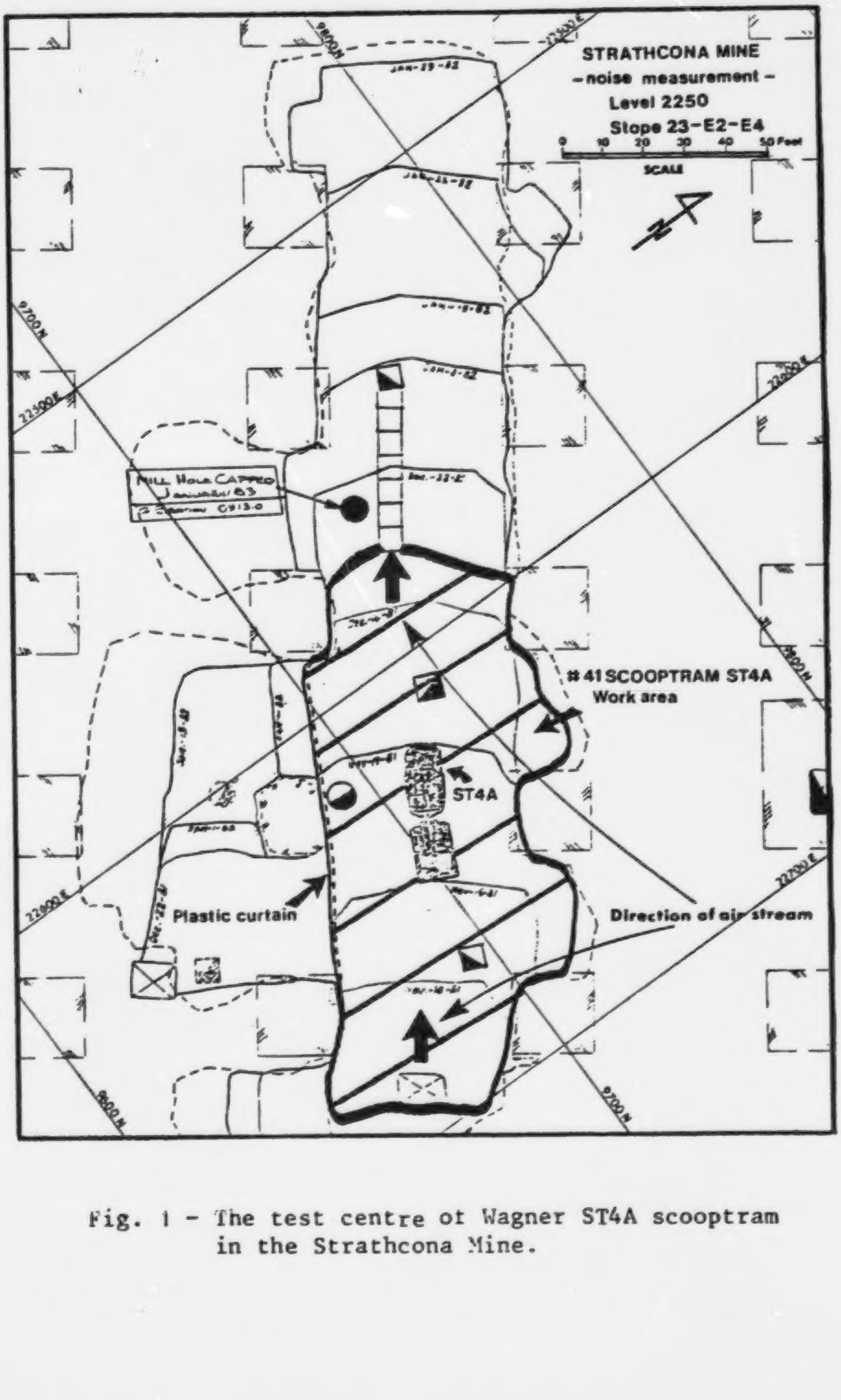
STRATHCONA MINE
-noise measurement -
Level 2250
Stope 23-E2-E4
0 10 20 30 40 50 Feet
SCALE
MILL HOLE CAPPED
JANUARY/83
#41 SCOOPTRAM ST4A
Work area
ST4A
Plastic curtain
Direction of air stream
9700 N
9600 N
22500 E
22600 E
22700 E

Fig. 1 - The test centre of Wagner ST4A scooptram in the Strathcona Mine.

exhaust outlet, and the levels of operator's exposure to this noise under three conditions (Fig. 2):

- scooptram without muffler or filter,
- scooptram with small and large filter,
- scooptram with filter, muffler and fume diluter.

2. To characterize the noise produced under the three above mentioned conditions and to recommend improvement of, or means for their control.

RESULTS OF MEASUREMENTS

Measurement results are presented in the noise spectrum in octave bands for a distance of 1 m from the left and right sides of the motor and for the operator's ear (Appendix A, 1-4). Also noise measurements in dBA were performed at the exhaust outlet and operator's ear, and each were then averaged over 1 min (Appendix B, 1-6).

OCTAVE BAND ANALYSIS

Measurements were performed using a Sound Level Meter which conforms with ANSI S1.4-1971 Type 1. Noise measurements in octave bands yielded the following results (Appendix A, 1-4): with the ST4A scooptram, spectrum differences between IDLE and W.O.T.* noise are well marked. However, an exception occurs at 31.5 Hz. The W.O.T. state of the engine has a high noise level at 125 Hz. The ST4A scooptram has almost equal values between filter 1 and filter 2 on the spectrum, and the results for the two are very similar. In both cases peaks occur at a frequency of 63 Hz. These peaks do not have a marked influence on overall noise in the A-network. In the case of the scooptram with filter, muffler and fume diluter two peaks occur: one from the fume diluter at its outlet, and the other at the operator's ear at a frequency of 125 Hz (most probably from the fume diluter inlet, Apendix A-4). Neither of

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*W.O.T. = Wide Open Throttle.

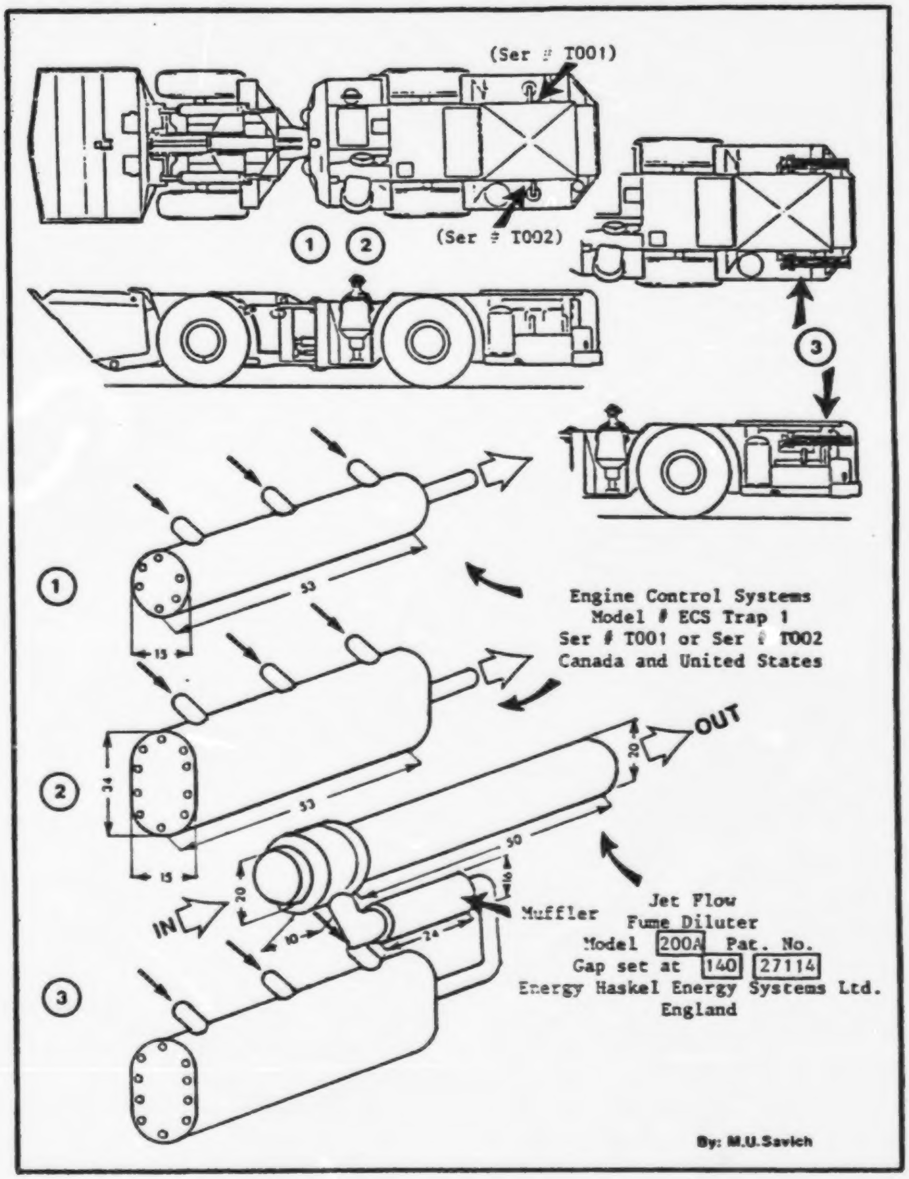

(Ser # T001)
(Ser # T002)
①
②
③
53
15
34
53
15
20
OUT
50
20
10
24
IN
Muffler
Jet Flow
Fume Diluter
Model 200A Pat. No.
Gap set at 140 27114
Energy Haskel Energy Systems Ltd.
England
Engine Control Systems
Model # ECS Trap 1
Ser # T001 or Ser # T002
Canada and United States
By: M.U.Savich

Fig. 2 - Exhaust treatment during tests:
1. Small filter, 2. Large filter,
3. Filter, muffler and fume diluter.

these two peaks has a marked influence on the A-network. This noise at the operator's ear can be reduced with deflectors mounted at the diluter's inlet to deflect the noise towards the outlet.

Engine noise at W.O.T. without filter has the highest level of noise, 110.12 dBA for both sides (Table 1). Filter, muffler and fume diluter decrease engine noise by 8 dBA to 102.25 dBA. The exception is the engine with filter 2 alone at its right side. Noise increases at the right hand side are likely because of the heterogenous* metal filter. Despite mounting a muffler and fume diluter,with the engine at idle, noise increases by 3.75 dBA at the operator's ear. This is understandable since the diluter's inlet points directly towards the operator. However, when the engine is at W.O.T. state, noise is lower by 4.25 dBA. This difference from IDLE to W.O.T. requires further investigation. During this test, impulse, impact and peak noise were also measured. In Table 2 it can be seen that relations are similar to those in Table 1. Left and right sides of the engine both yield the same or similar results.

A-WEIGHTED SOUND PRESSURE LEVEL (SPL_s) MEASUREMENT

A detailed level and time study, using a sample rate of 4/sec averaged over 1 min, may provide enough data to arrive at a statistical distribution or time history graph in the computer, with a very high confidence in results (Appendix B, 1-6). S. Bandopadhyad and R.V. Ramani, in their analysis of diesel exhaust dispersions in underground airways have adopted the method of averaging over 1 min as being the best one (2). A-weighted sound pressure levels were measured with Type 2 instruments, complying with ANSI S1.4 - 1971.

In this test, exhaust noise at both sides of the motor and total noise

---

* Metal filters pressed in the shop for R & D work and not for a normal production run.

Table 1 - Noise levels in A-weighted network of ST4A scooptram under different testing conditions.

Condition of Test	Engine Status	Noise in dBA							
		Scooptram (Distance 1 m)						Operator	
		Left Side		Right Side		Both Sides			
		Meas'd	Est'd	Meas'd	Est'd	Meas'd	Est'd	Meas'd	Est'd
Without Filter	Idle	90.75	90.6	91	91.4	90.87	91	83.75	84.2
	W.O.T.	112.25	112.7	108	108.7	110.12	110.7	101.75	101.8
With Filter-1	Idle	88.5	88.9	88.5	88.7	88.5	88.8	81	81.2
	W.O.T.	104.25	104.6	103.25	103.4	103.75	104	96.5	96.1
With Filter-2	Idle	87.5	87.7	88	89	87.75	88.35	82	81.9
	W.O.T.	103.5	104.3	105	105.1	104.25	104.65	97	97.4
With Filter Muffler and Fume Diluter	Idle	86	86.4	87	87.6	86.5	87	87.5	87.2
	W.O.T.	102	102.2	102.5	102.6	102.25	102.4	97.5	97.4

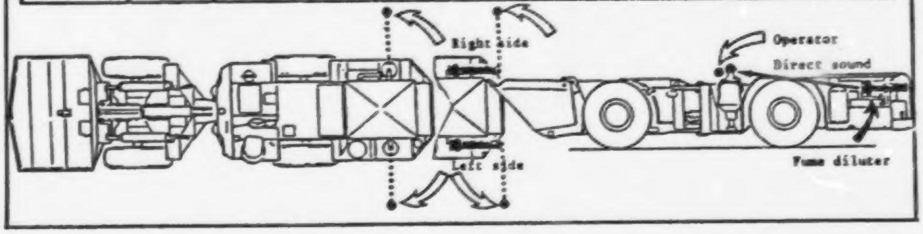
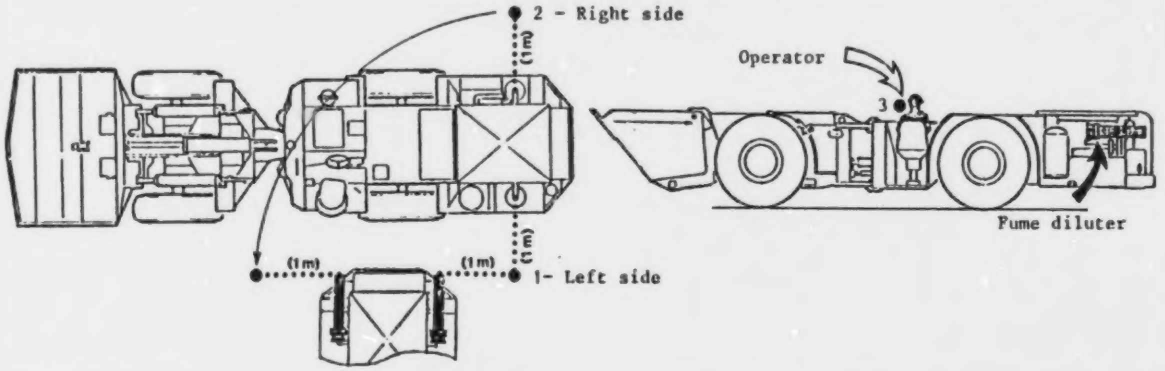


Table 2 - The noise data: impulse, impact hold and peak hold at left and right side, exhaust outlets and the operator's ear during octave band measurement.

Engine Status	Position	Level in dB											
		Condition of Test											
		Without Filter			With Filter-1			With Filter-2			With Filter, Muffler and Fume Diluter		
		Impulse	Impact Hold	Peak Hold	Impulse	Impact Hold	Peak Hold	Impulse	Impact Hold	Peak Hold	Impulse	Impact Hold	Peak Hold
Idle	1	92.5	93.5	106.75	89	90.5	103.25	88.5	89.7	102	88	89	101
	2	92	92.5	105.5	89	90.25	103.25	90	91	102.5	87	87.5	100
	3	84.5	86	96.75	81.5	83	94.75	83	88.5	95.5	83	84	96
W.O.T.	1	112.25	113	124.5	104.5	105.5	117	104	104.5	117	103.5	103.5	115
	2	108.75	109.75	121.5	103.5	104.5	116.25	105.5	106	118.5	103	103	115.5
	3	102	102.5	114.5	96.5	97.5	105.25	97.5	98	99.5	97.5	98	109.5



at the operator's ear were measured. Using a special attachment the microphone was mounted 16 cm behind the pipe of the exhaust outlet. The microphone was covered with a windscreen to protect it from emitted gases and impurities. IDLE and W.O.T. noise was measured while the ST4A scooptram remained stationary, and also under simulated working conditions (L.H.D.). IDLE and W.O.T. measurements were done simultaneously with the octave band analysis which has already been discussed.

Measured results are displayed in Appendix B, 1-6. To ensure better absolute and relative values at the exhaust outlet, all results were obtained by using the same instruments (Logger type = dB-301/16, Serial Numbers: 3428, 3146, 3425 and 3421). In the last two measurements, scooptram with filter 2 and scooptram with filter, muffler and fume diluter, the above mentioned instrument with Serial Number 3421 was used in order to maximize precision. All instruments were calibrated before and after completing the measurements. To characterize noise, 1 min averaging levels were deployed, and the following engine states were evaluated: IDLE, W.O.T. and working condition. In Appendix B, 1-6, the mean and standard deviation were calculated for each motor state. Results are sorted in Table 3. From these results it is clear that the ST4A scooptram with filter, muffler and fume diluter provides the best attenuation on both exhaust pipes. On the left side the attenuation is from 11.3 dBA to 15.3 dBA. At the operator's ear, attenuation is a lot less, from 1.9 dBA to 4.8 dBA. The fume diluter produces noise from 1.7 to 1.6 dBA more than when only filter 2 is installed. While the motor is in its work state, the noise level is the same with filter 2. The resulting confidence was evaluated using a t-distribution test. In Table 4 there are calculated value lengths of a 99% confidence interval in dBA. In only 3 cases is the length of the confidence interval longer. Two of the cases occur when filter 2 is on the right side of

Table 3 - A-weighted sound pressure levels (SPL_s) of the Wagner ST4A scooptram at left and right side, exhaust outlets and the operator's ear. Engine at IDLE, W.O.T. and Work states.

Condition of Test	Engine Status	Minutes	Noise in dBA							
			Scooptram						Operator (3)	
			Left Side (1)		Right Side (2)		Both Sides			
			Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Without Filter	Idle	33	102.76	0.61	101.86	0.86	101.91	1.13	86.24	1.25
	W.O.T.	28	119.93	1.46	116.93	1.7	118.43	2.26	102.64	1.73
	Work	31	116.58	1.18	112.29	1.04	114.44	2.43	100.94	1.18
With Filter-1	Idle	27	97.22	0.97	97.93	1.21	97.57	1.14	84.7	2.46
	W.O.T.	26	108.69	0.97	109.04	1.7	108.87	1.4	96.92	1.52
	Work	32	105.63	1.18	103.91	1.04	104.77	1.51	97.41	1.1
With Filter-2	Idle	14	97	-	96.64	0.5	96.82	0.39	82.64	2.71
	W.O.T.	11	109.91	0.83	110.09	1.64	110	1.27	95.18	0.4
	Work	28	106.54	1.14	104.43	1.62	105.46	1.75	96.14	0.36
With Filter Muffler and Fume Diluter	Idle	13	91.46	0.52	95	-	93.23	1.84	84.31	0.48
	W.O.T.	12	106.67	0.49	108	0.74	107.33	0.92	96.75	0.45
	Work	30	101.3	1.09	104.17	0.91	102.75	1.96	96.13	0.86

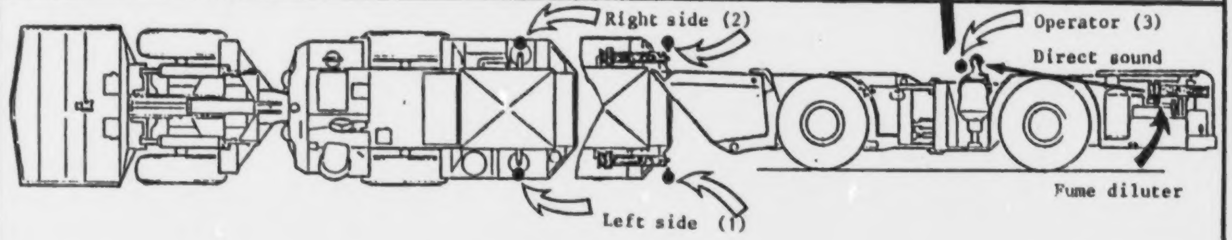
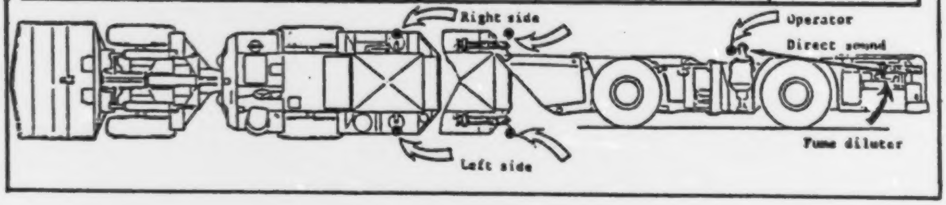


Table 4 - Results of the t-distribution test.

Condition of Test	Engine Status	Minutes	Length of 99% confidence interval in dBA			
			Scooptram			Operator
			Left Side	Right Side	Both Sides	
Without Filter	Idle	33	0.54	0.78	1.02	1.12
	W.O.T.	28	1.52	1.78	2.36	1.8
	Work	31	1.1	0.96	2.25	1.1
With Filter-1	Idle	21	1.04	1.3	1.22	2.6
	W.O.T.	26	1.06	1.86	1.53	1.65
	Work	32	1.08	0.95	1.37	1.0
With Filter-2	Idle	14	-	0.84	0.63	4.36
	W.O.T.	11	1.5	3.13	1.21	0.76
	Work	28	1.2	1.7	1.83	0.22
With Filter Muffler and Fume Diluter	Idle	13	0.88	-	3.12	0.26
	W.O.T.	12	0.88	1.3	1.65	0.8
	Work	30	1.1	0.92	1.97	0.32


Right side
Left side
Operator
Direct sound
Fume diluter

the motor at W.O.T.; and one at the operator's ear at IDLE. Perhaps this is because the duration of observations was shorter or due to the operator moving his head. The third case is when the motor is equipped with filter, muffler and fume diluter on both sides of the scooptram. It has a confidence interval slightly greater than 3 dBA, which can be explained by uneven metal filling of filters or the small dimensions of resonant mufflers.

The range of tolerance limits for a Type 2 Sound Level Meter is from plus 3.5 dB or minus 4.0 dB in the low frequencies, to plus or minus 6.5 dBA at 8000 Hz. Sound level tolerance limits are widest at 4000 to 8000 Hz, and the noise level reading is greatly influenced by these limits, especially at the higher frequencies (Table 5).

In light of the foregoing, an arbitrary decision was made to use a ± 2 dBA limit on overall noise dosimeter accuracy (3). This gives another reason for a high degree of confidence in all the results presented in Table 3 and tested in Table 4. All lengths of 99% confidence intervals in dBA are under 4 dBA, except where there is 4.36 dBA at the operator's ear.

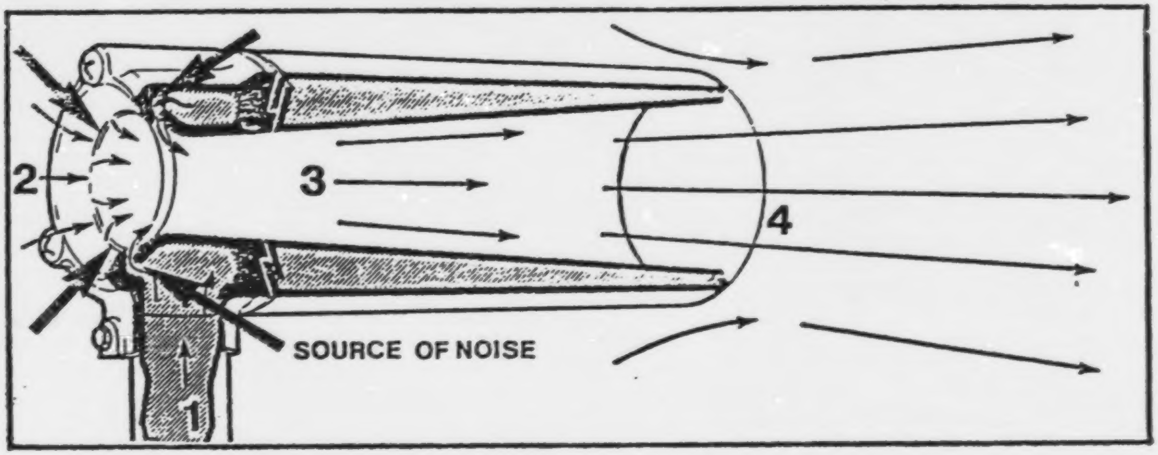
NOISE PROBLEMS OF FUME DILUTER

Completed analyses clearly show that the fume filter increases noise at the operator's seat. The source of noise is a radial connection which releases fumes through the annular gap to accelerate over the aerofoil surface (Fig. 3). Marked increases of noise occur at 1000 Hz and 2000 Hz (Appendix A, 4). Lower frequencies have no effect in increasing noise. This is proof that noise at the operator's set can be decreased by using a saucer-shaped deflector, with its concave surface pointed at the throat of the tube (Fig. 4).

Ideal deflector size and its distance from the throat of the fume diluter can be ascertained only through further experiments. Installed ECS

Table 5 - The effect of instrument tolerance limits

Sound Level Meter ANSI S1.4-1871, Type 2	
Frequency, Hz	A-Weighting dB
31.5	+3.5, -4.0
63	+3.0, -3.0
125	+2.5, -2.5
250	+2.5, -2.5
500	+2.0, -2.0
1000	+2.0, -2.0
2000	+3.0, -3.0
4000	+5.5, -4.5
8000	+6.5, -6.5


2
3
4
1
SOURCE OF NOISE

(1) Primary supply entry (3) Induced air mixes
(3) Secondary supply (4) High velocity air emitted

Fig. 3 - Fume diluter (4).

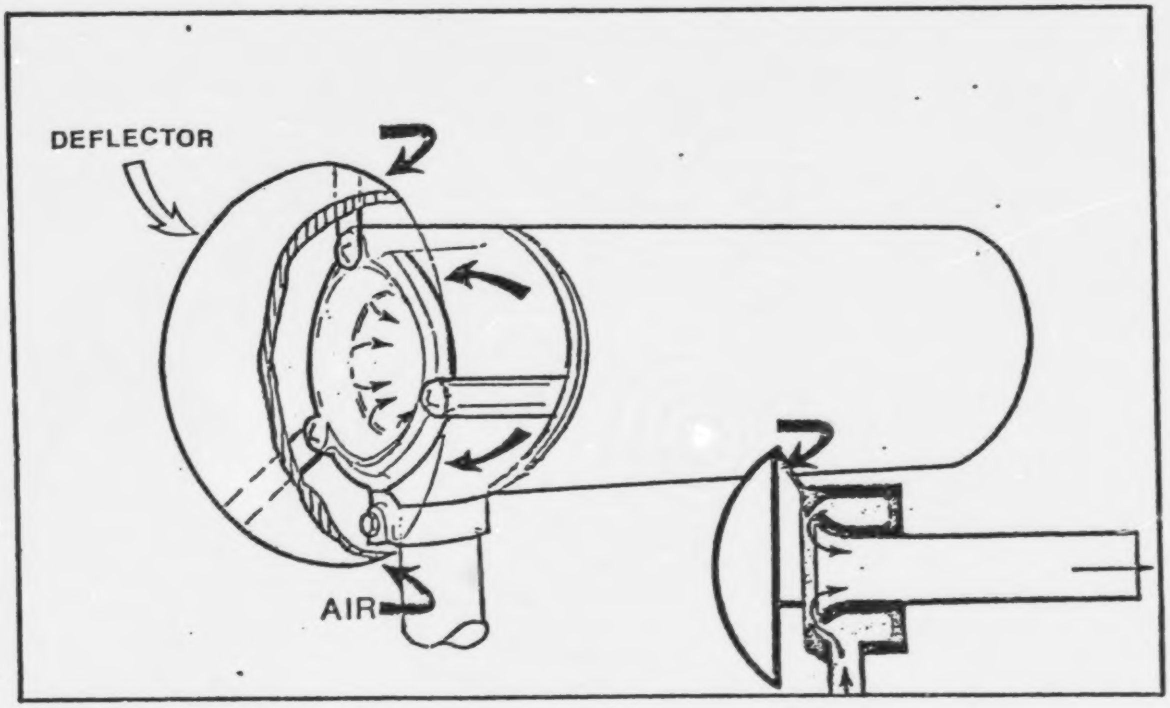

DEFLECTOR
AIR

Fig. 4 - Deflector in fume diluter.

resonant mufflers should be further tested without fume diluters, as should fume diluters without the resonant mufflers. Should this demonstrate that the muffler is inefficient in tandem with the filter and fume diluter, more attention will have to be given to the fume diluter. Modifying the fume diluter and deploying it in tandem with the resonant muffler could make a good technical solution. Close approximations of the design chart have shown that new attempts can be made at decreasing noise in this system. Experimental work, using the design chart for lined duct or resonant mufflers will greatly reduce the theoretical work required for improved design (5).

CONCLUSION

This is the first study which concentrates exclusively on the noise of Load- Haul-Dump (LHD) vehicles emitted at the exhaust outlet under different engine states in relation to the operator's site. The study had two objectives:

1. to determine what noise levels the Wagner ST4A scooptram produces at the exhaust outlet and the levels of operator's exposure to this noise under four conditions:
   - scooptram without muffler or filter;
   - scooptram with small filter;
   - scooptram with large filter;
   - scooptram with large filter, muffler and fume diluter.
2. To recommend improvements or means for their control.

Measurement results demonstrate that the combination of filter, muffler and fume diluter provides maximum abatement of exhaust noise - around 8 dBA - for both sides of the outlet. The operator is exposed to a higher level of noise when a fume diluter is built into the entire system. This is understandable, since the fume diluter is a new source of noise, noise which must be decreased. Studying this problem is fairly complex and demands lengthy experimentation. As a provisional measure a saucer-shaped deflector is recommended. This deflector must be mounted at the inlet of the fume diluter to protect the operator from the noise. After this experimental confirmation, this method is recommended for practical and permanent utilization.

These results and their evaluation show that:

1. The use of filters alone can reduce the noise level at the operator's ear at W.O.T. to within 5 dBA of the noise standard.
2. Fume diluters add noise because of their design and this noise can be reduced with further evaluation and initially with a noise deflector.
3. Noise, 1 m from the scooptram, is reduced by 11.7 dBA from exhaust treatment along, and will reduce the noise hazard for other personnel in the stope.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of R. Van Ooteghen of the Mines Accident Prevention Association of Ontario for taking the measurements.

The support of Falconbridge Ltd., through D. Cornett, Mine Superintendent, S. Schultz, Ventilation Engineer, J. Calvert, Master Mechanic, and D. McPhee, Occupational Health Technician is also acknowledged.

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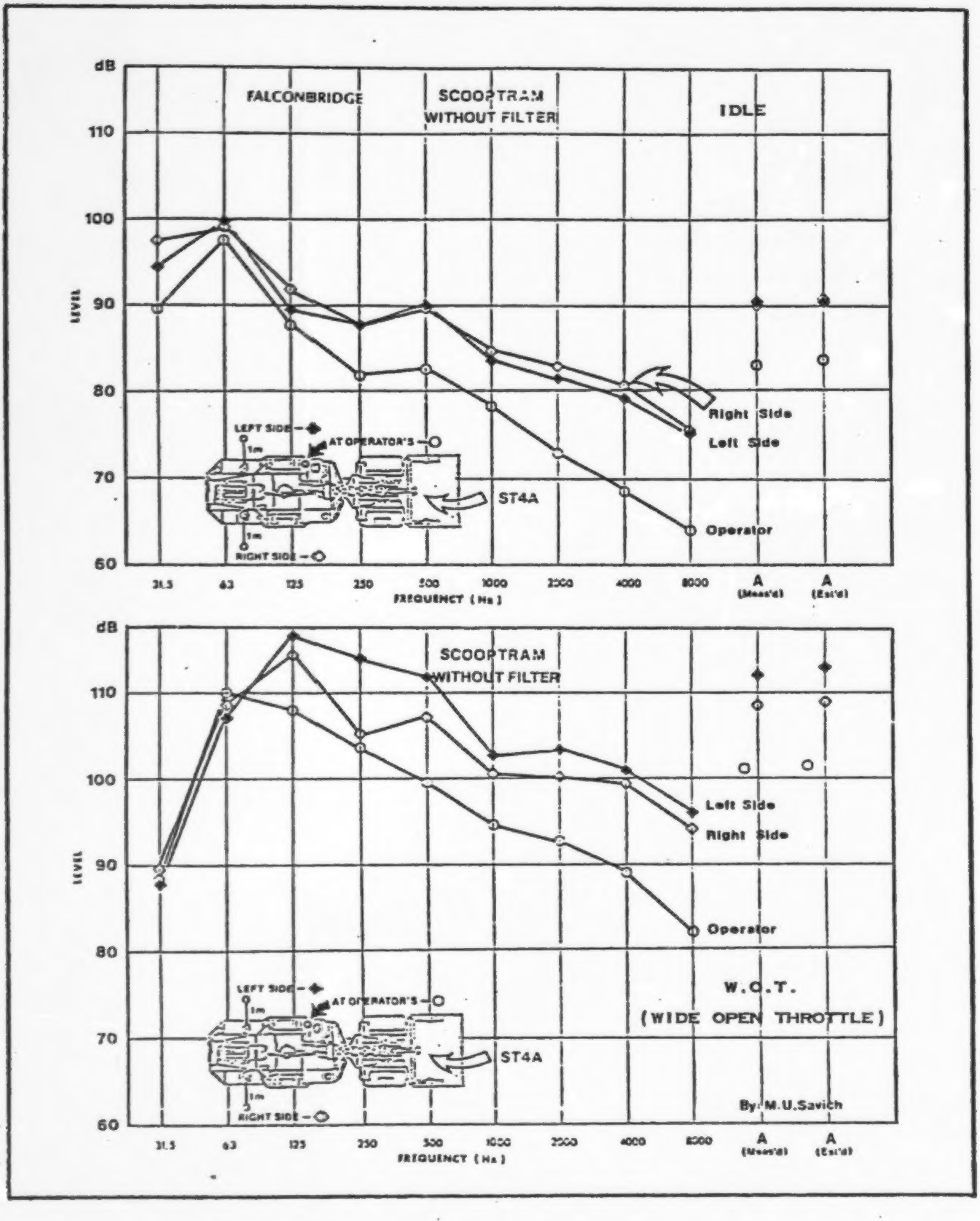
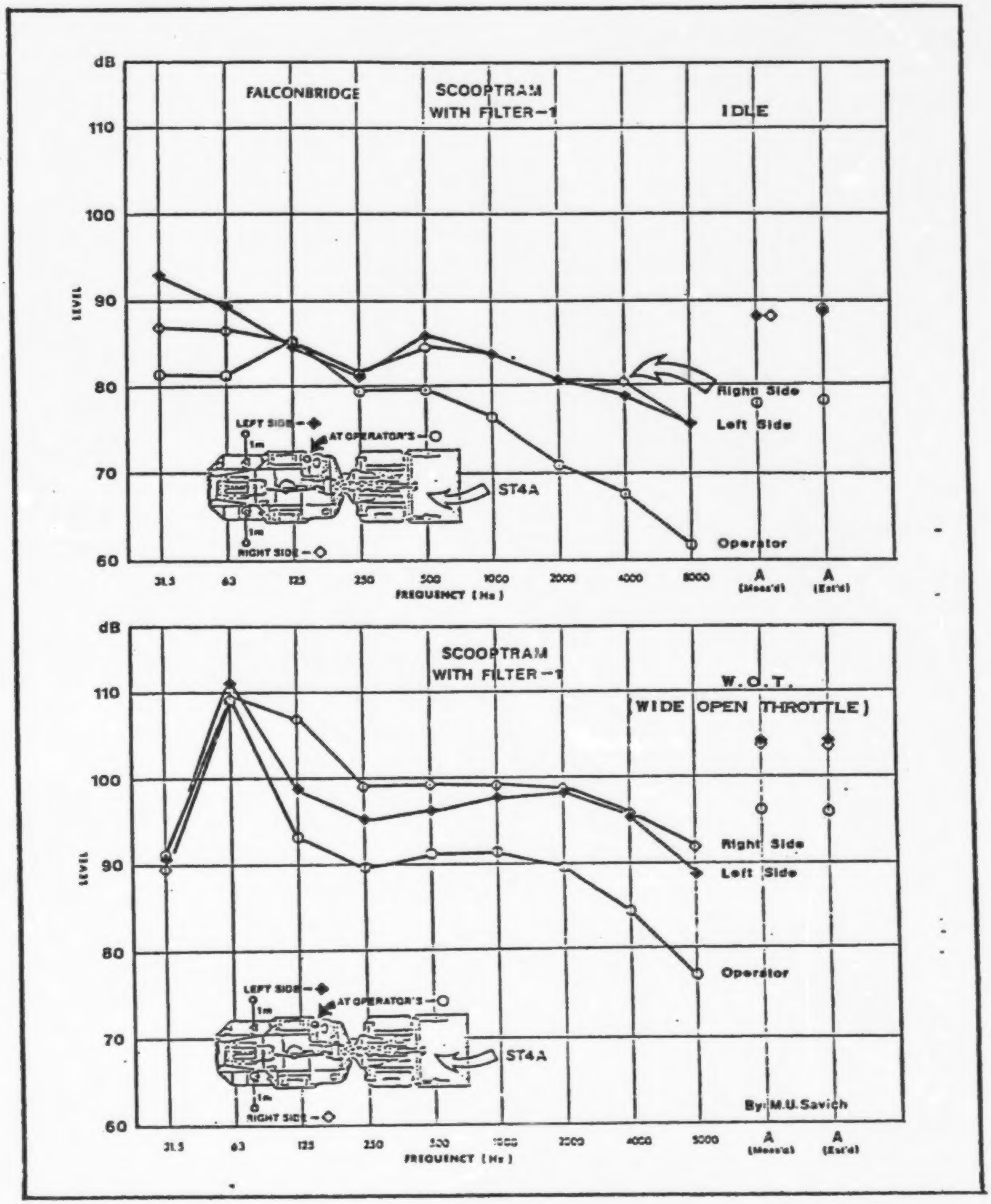
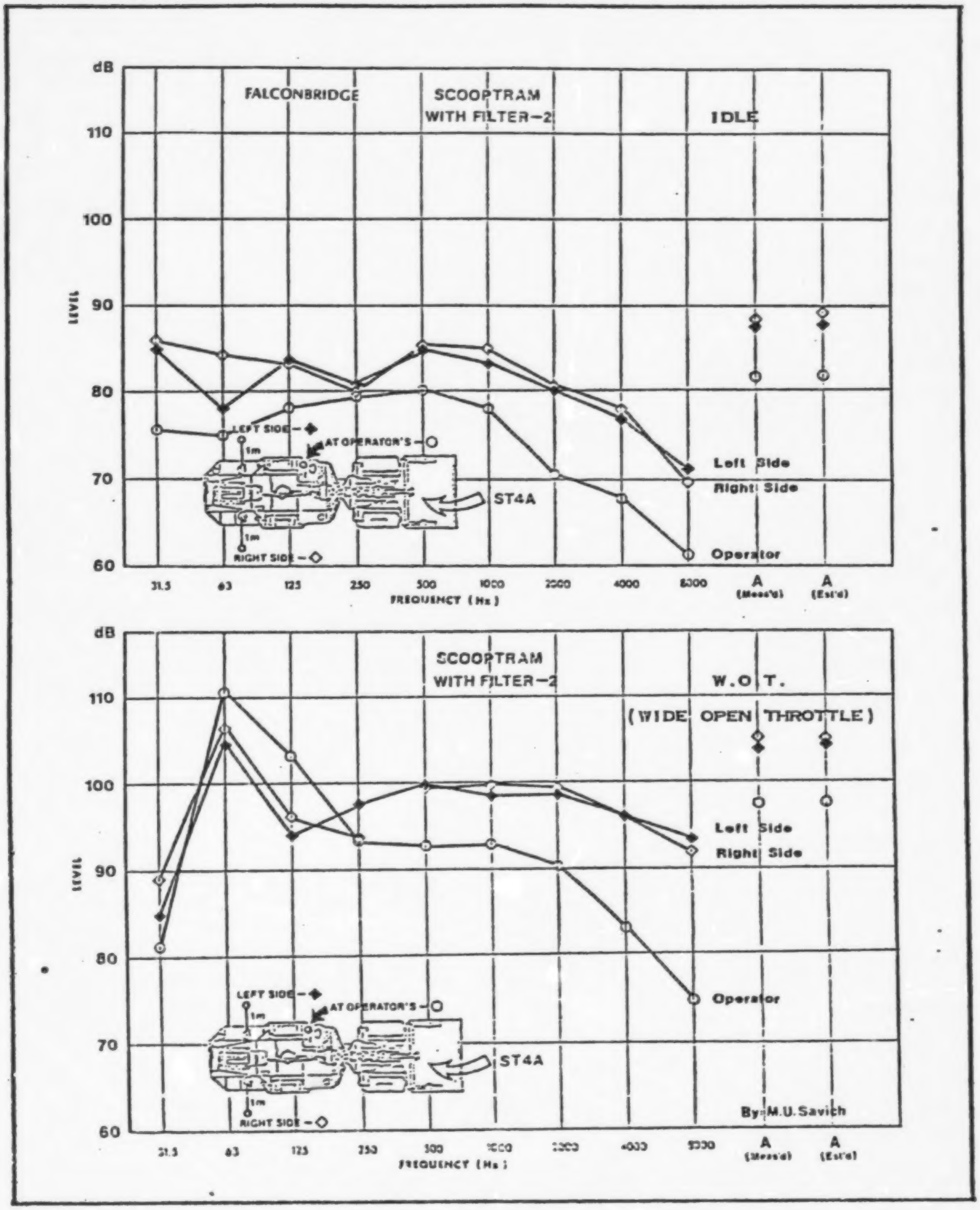


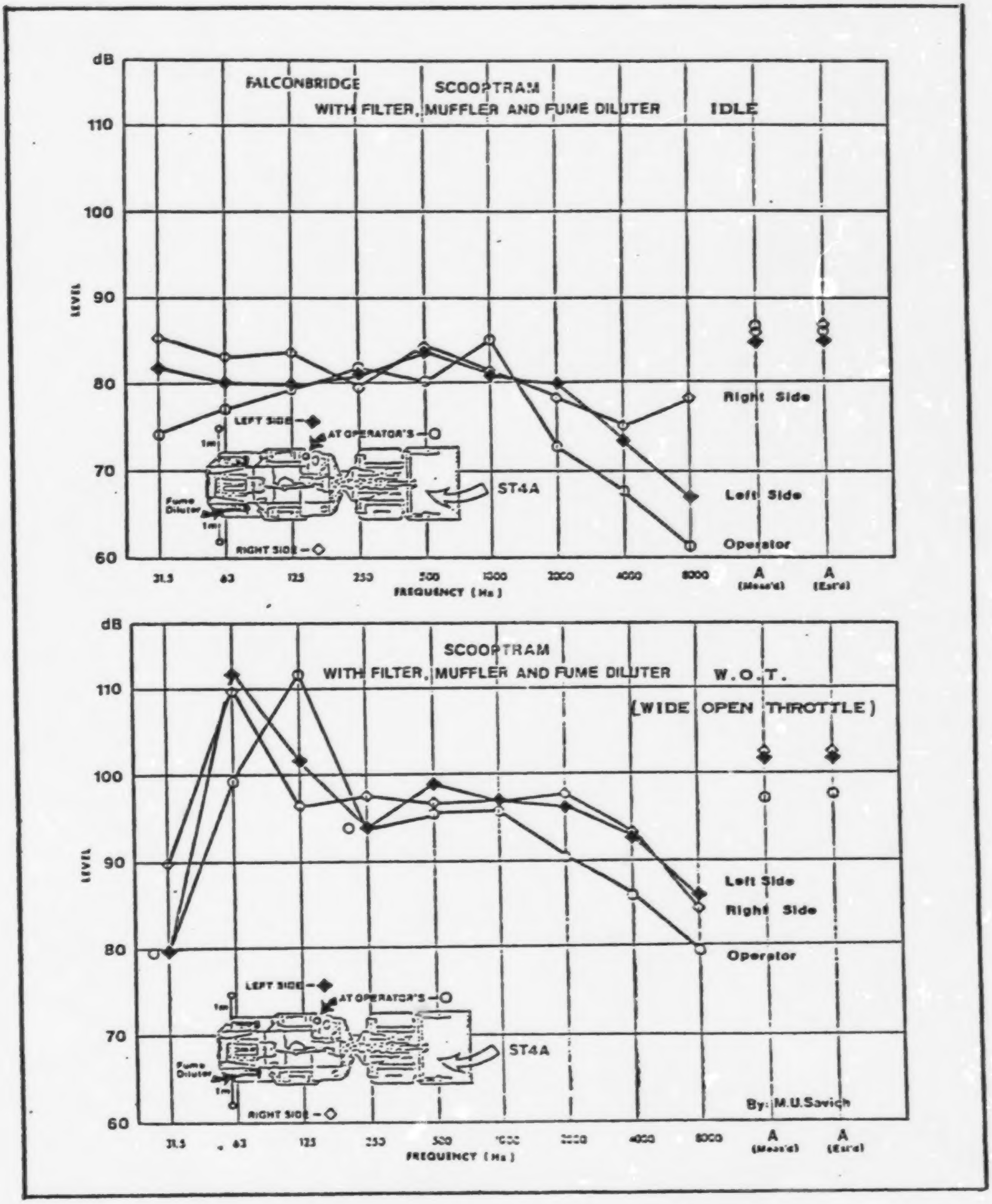
The noise spectrum in octave bands, produced by the ST4A scooptram without filter at engine states IDLE and W.O.T.



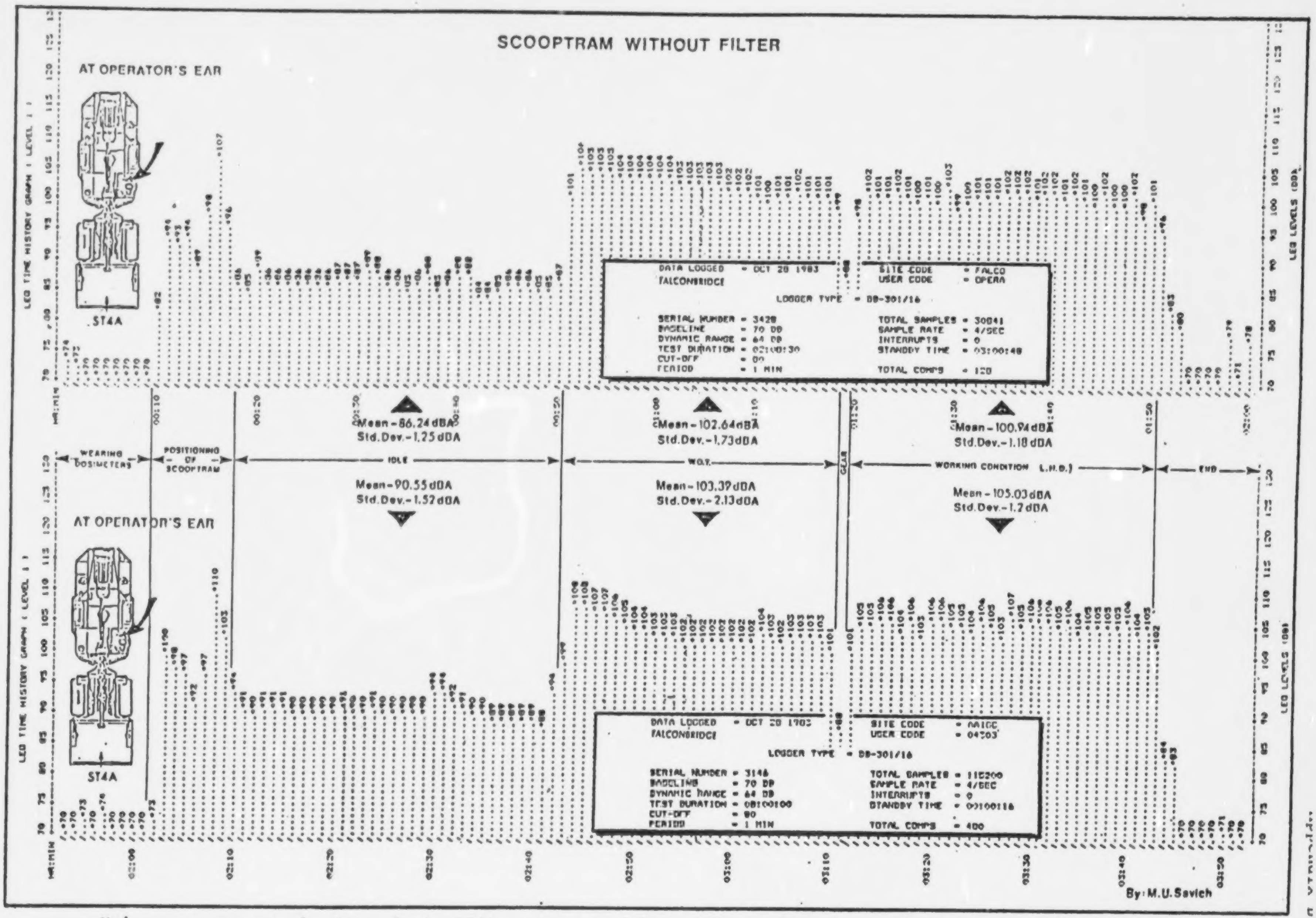
The noise spectrum in octave bands, produced by the ST4A scooptram with filter 1 at engine states IDLE and W.O.T.



The noise spectrum in octave bands, produced by the ST4A scooptram with filter 2 at engine states IDLE and W.O.T.



The noise spectrum in octave bands, produced by the ST4A scooptram with filter, muffler and fume diluter at engine states IDLE and W.O.T.



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FALCONBRIDGE                          USER CODE      = OPERA

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CUT-OFF        = 00
PERIOD         = 1 MIN                TOTAL COMPS    = 120
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FALCONBRIDGE                          USER CODE      = 04303

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SERIAL NUMBER  = 3146                 TOTAL SAMPLES  = 115200
BASELINE       = 70 DB                SAMPLE RATE    = 4/SEC
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TEST DURATION  = 08:00:00             STANDBY TIME   = 00:00:16
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PERIOD         = 1 MIN                TOTAL COMPS    = 400
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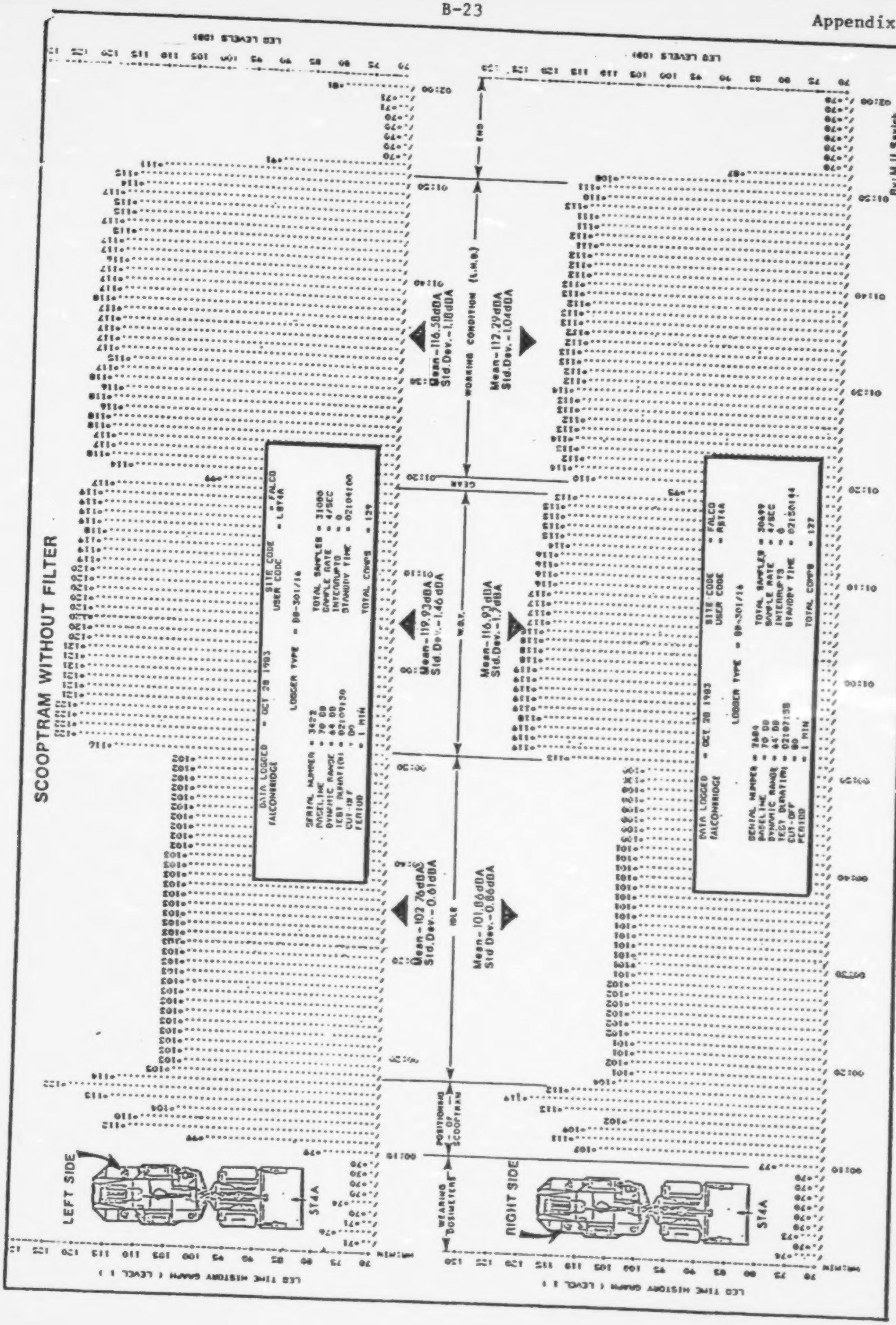
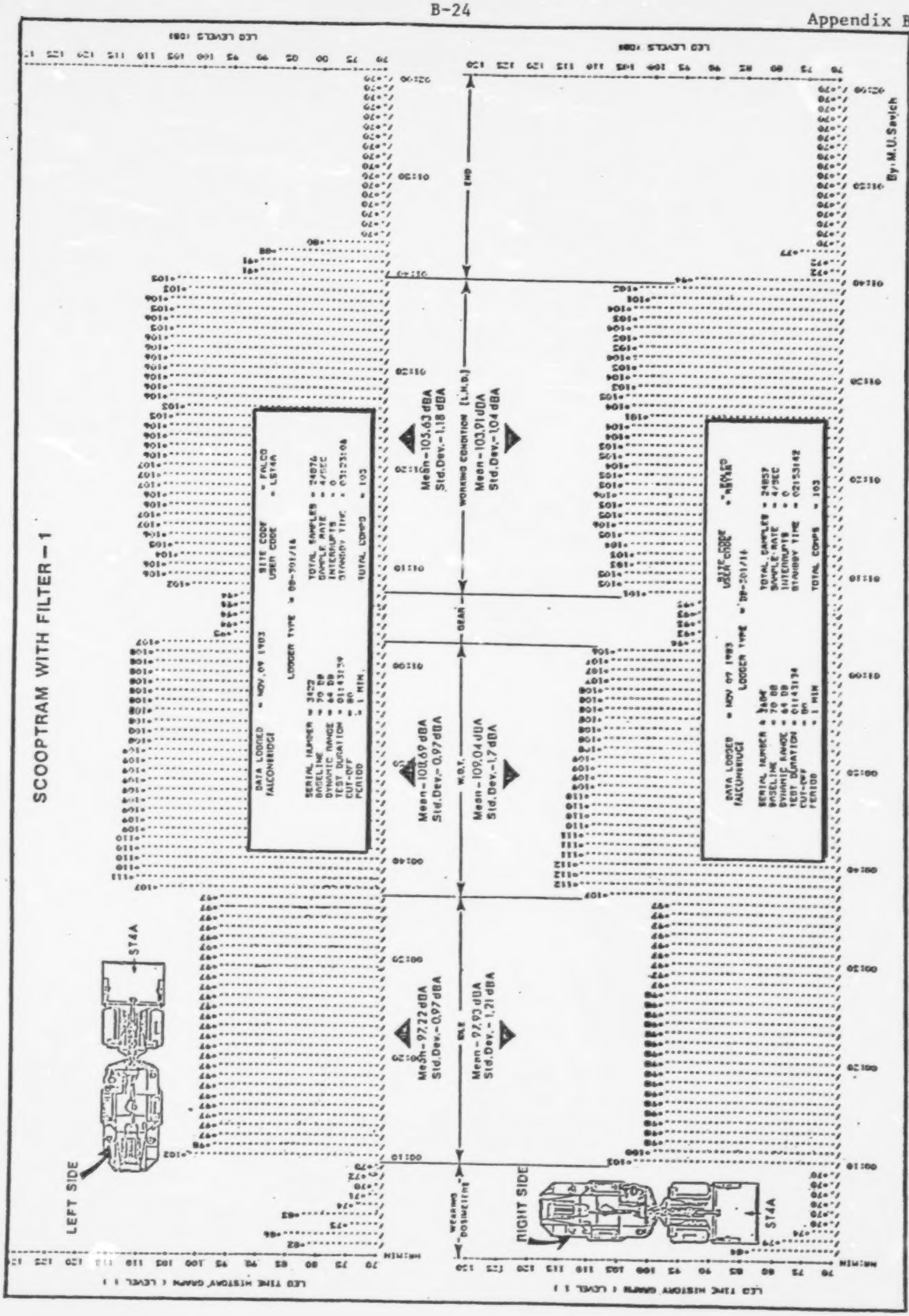
Noise measurements in dBA, of the ST4A scooptram without filter, from left and right side exhaust outlets.

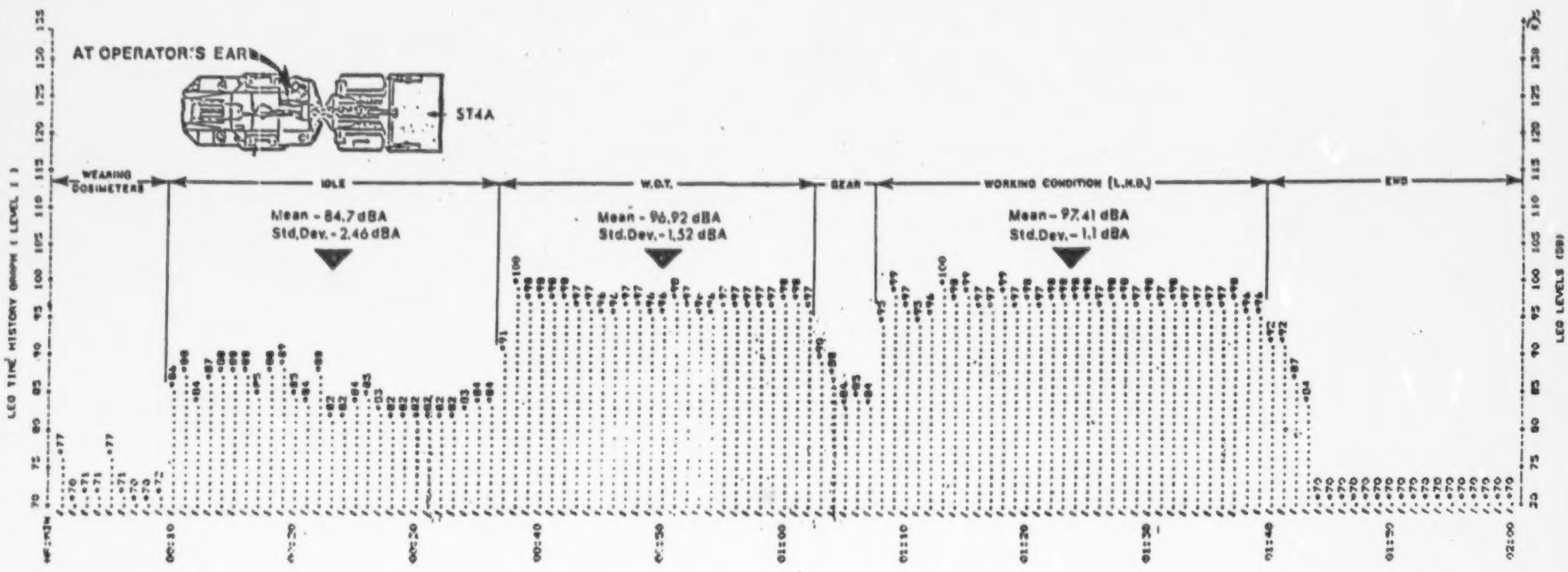


Noise measurements, in dBA, of the ST4A scooptram at operator's ear. These mea



Noise measurements, in dBA, of the ST4A scooptram, from left and right side exhaust outlets.

SCOOPTRAM WITH FILTER – 1



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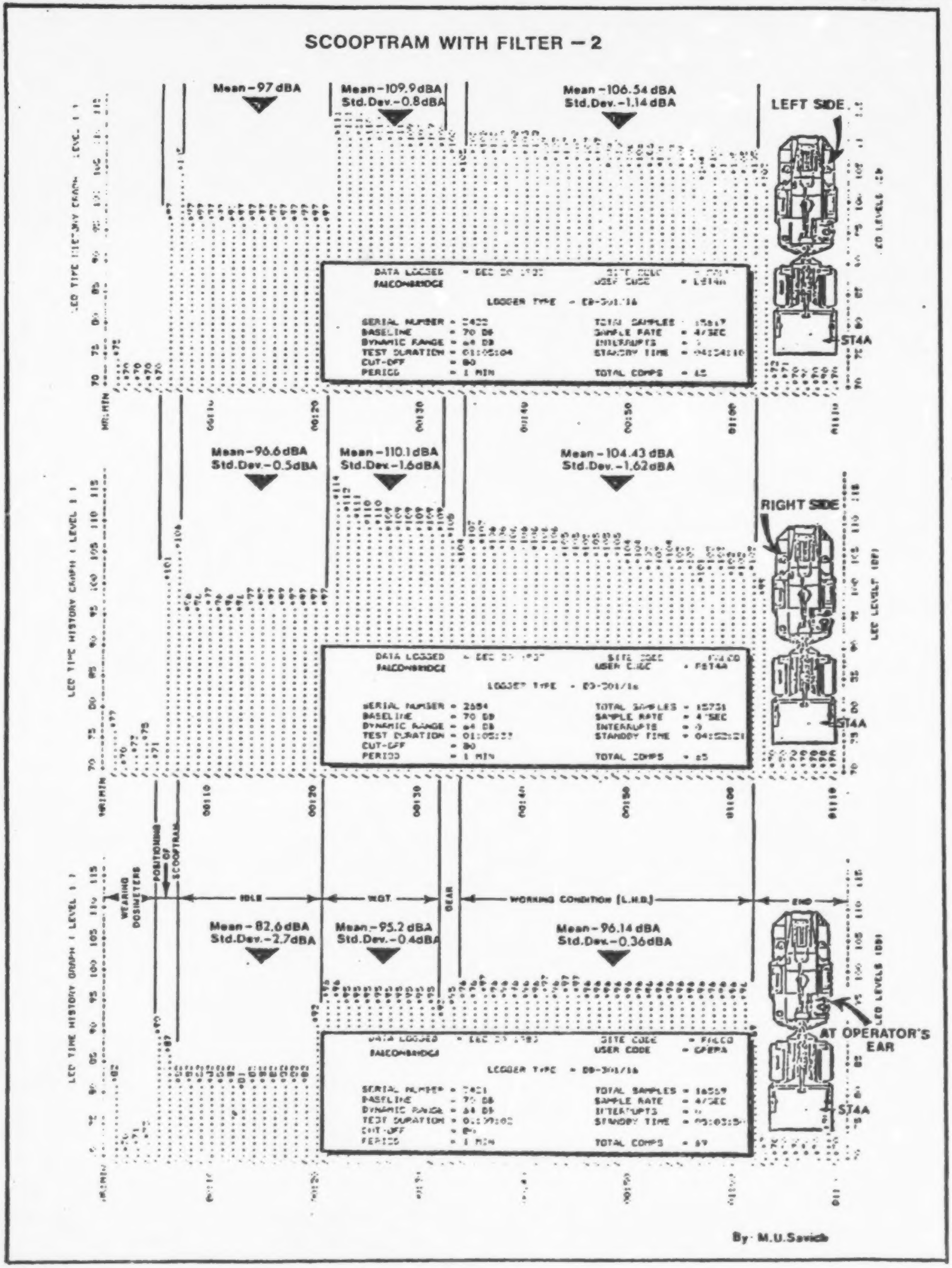
FALCONBRIDGE                          USER CODE     = OPERA

                   LOGGER TYPE  = DB-301/16

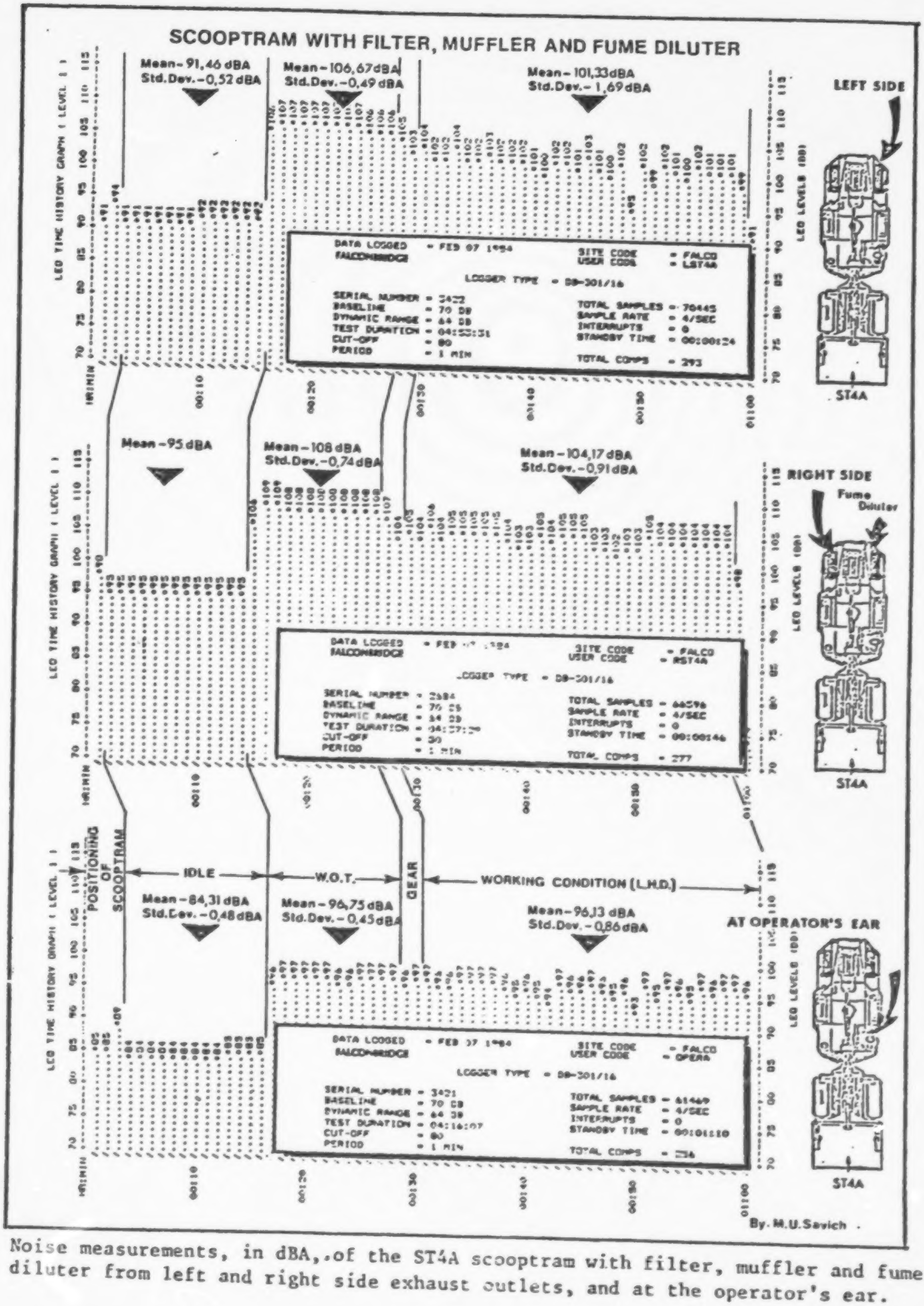
SERIAL NUMBER = 3425                  TOTAL SAMPLES = 24839
BASELINE      = 70 DB                 SAMPLE RATE   = 4/SEC
DYNAMIC RANGE = 64 DB                 INTERRUPTS    = 0
TEST DURATION = 01:43:30              STANDBY TIME  = 03:30:57
CUT-OFF       = 80
PERIOD        = 1 MIN                 TOTAL COMPS   = 103
```

Noise measurements, in dBA, of the ST4A scooptram at the operator's ear.

By: M.U. Savich


SCOOPTRAM WITH FILTER – 2

Noise measurements, in dBA, of the ST4A scooptram with filter 2 from left and right side exhaust outlets, and at the operator's ear.



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USER CODE = LST4A
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DYNAMIC RANGE = 64 DB
TEST DURATION = 04:53:51
CUT-OFF = 80
PERIOD = 1 MIN
TOTAL SAMPLES = 70445
SAMPLE RATE = 4/SEC
INTERRUPTS = 0
STANDBY TIME = 00:00:24
TOTAL COMPS = 293

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FALCONBRIDGE
SITE CODE = FALCO
USER CODE = RST4A
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DYNAMIC RANGE = 64 DB
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CUT-OFF = 80
PERIOD = 1 MIN
TOTAL SAMPLES = 66596
SAMPLE RATE = 4/SEC
INTERRUPTS = 0
STANDBY TIME = 00:00:46
TOTAL COMPS = 277

DATA LOGGED = FEB 07 1984
FALCONBRIDGE
SITE CODE = FALCO
USER CODE = OPERA
LOGGER TYPE = DB-301/16
SERIAL NUMBER = 3421
BASELINE = 70 DB
DYNAMIC RANGE = 64 DB
TEST DURATION = 04:16:07
CUT-OFF = 80
PERIOD = 1 MIN
TOTAL SAMPLES = 61469
SAMPLE RATE = 4/SEC
INTERRUPTS = 0
STANDBY TIME = 00:01:10
TOTAL COMPS = 256

Noise measurements, in dBA, of the ST4A scooptram with filter, muffler and fume diluter from left and right side exhaust outlets, and at the operator's ear.

GLOSSARY

A-Weighted Sound Level: The A-weighting network of a sound level meter is a standardized frequency-dependent filter which discriminates against frequencies below 1,000 cycles per second and above 4,000 cycles per second. The A-weighted sound level is the single number that one would read from a sound level meter with the A-weighting network. The unit of measure is the decibel, and, to note the A-weighting, it is abbreviated dBA. The three networks are designated A, B and C, according to ANSI S1.4 - 1971.

Acoustic Absorption: The change of sound energy into some other form.

Analyzer: A combination of a filter system and a system for indicating the relative energy that is passed through the filter system. The filter is usually adjustable so that the signal applied to the filter can be measured in terms of the relative energy passed through the filter as a function of the adjustment of the filter response-vs-frequency characteristic. This measurement is usually interpreted as giving the distribution of energy of the applied signal as a function of frequency.

Damping: The dissipation of energy with time or distance.

Decibel (dB): A dimensionless unit of measure of the ratio of two quantities, each of which is equal to or proportional to power. If P_1 and P_2 are 10 times the logarithm to the base 10 of the ratio of two such quantities, then P_1/P_2 has the dimensions of decibels.

Directivity: The directivity of a source describes the extent to which the source radiates more sound in some directions than others.

Fast: Fast is the way of reading through intermittent noise to investigate what a steady noise source contributes. It means that the time constant of the instrument is 200 m/sec. That is, if the pressure abruptly changed from one dynamic pressure to another and stayed there 200 m/sec before returning to its original level, the instrument reported the difference in level, assuming that its response in the meter and driving circuit were no slower than anything else in the meter.

Filter: A device for separating components of a signal on the basis of their frequency.

Frequency: The time rate of repetition of a periodic phenomenon. The frequency is the reciprocal of the period of a pure tone. Frequency is given in Hertz (Hz).

Gaussian Distribution (Normal Distribution): A particular amplitude distribution of fundamental importance in the theory of probability. Its histogram is the familiar 'bell-shaped curve'. It describes many natural phenomena, and most stationary acoustic noise that is not periodic has an essentially Gaussian distribution.

Hard Surface: A surface which is a poor absorber of sound.

Histogram: Graph of an amplitude density distribution.

Idle Speed: The engine's low idle speed as specified by the manufacturer (see SAE J35+ and J1003*).

Impact: A single collision of one mass in motion with a second mass which may be either in motion or at rest.

Impact in Acoustic: See Peak.

Impulse: Impulse noise is supposed to represent what happened in the inter esting 35 m/sec. Also defined as a change of sound pressure of 40 dB or more within 0.5 sec. (European countries make use of this setting and write laws where it is important.)

Isolation: Isolation is a reduction in the capacity of a system to respond to an excitation, attained by the use of a resilient support.

Kilohertz (kHz): 1,000 Hz.

Level: In acoustics, the level of a quantity is the logarithm of the ratio of that quantity to a reference quantity of the same kind. The base of the logarithm, the reference quantity, and the kind of level must be specified. Levels are always expressed in decibels (dB).

Mean: The mean is a value such that the sum of deviations of observations from it is zero; it is thus the sum of the observations divided by their number:

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

where x_i is an observation or measurement, n the total number of observations, and $\overline{x}$ the mean.

Microphone: An electroacoustic transducer that responds to sound waves and delivers essentially equivalent electric waves.

N(newton): The base unit of force, $mkgs^{-2}$.

Noise: Any undesired sound or any erratic, intermittent, or statistically random oscillation.

Noise Level:

1. The level of noise, the type of which must be indicated by further modifier or context.

Note: The physical quantity measured (e.g., voltage), the reference quantity, the instrument used, and the bandwidth or other weighting

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+ SAE J35 - Diesel smoke measurement, procedure recommended practice.

* SAE J1003 - Diesel engine emission, measurement procedure - recommended practice.

characteristic must be indicated.

2. For airborne sound, unless specified to the contrary, noise level is the weighted sound pressure level called sound level; the weighting must be indicated.

Noise Reduction: The difference in decibels between the sound pressure level on either side of a boundary construction is defined as the noise reduction (NR). Noise reduction can also refer to the number of dB by which sound pressure levels are reduced in a single space or at a fixed location due to introduction of noise control treatments.

Octave: The frequency interval in Hz or cycles per second between two sounds having a frequency ratio of two.

Octave Band: A frequency range bounded by upper and lower frequency limits f_u and f_1, where $f_u = 2f_1$. Octave bands are usually specified by their geometric mean frequency called the band center frequencies. The standard octave bands covering the audible range are designated by the following centre frequencies: 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, and 16,000 cycles per second (Hz).

Pa(pascal): The base unit of pressure ($Pa = N/m^2$).

Peak: Impact (or peak) is somewhat more understandable. The meter has a rise time of about 20 μsec and drives the peak it found into an amplifier. The amplifier, in turn, drives a 'remember' circuit that tells you the peak is reached. Have more faith in 'peak' than in 'impulse'.

Pure Tone: Sound wave whose sound pressure at a point varies sinusoidally with time and is characterized by its singleness of pitch. The time interval for one complete cycle of the sinusoidal pressure variation is known as the period.

Reverberation:

1. The persistence of sound in an enclosed space, as a result of multiple reflections after the sound source has stopped.

2. The sound that persists in an enclosed space, as a result of repeated reflection or scattering, after the source of sound has stopped.

Note: The repeated reflections of residual sound in an enclosure can alternatively be described in terms of the transient behaviour of the modes of vibration of the medium bounded by the enclosure.

Reverberant Field: That part of the radiated sound field where the waves reflected from the boundaries of the enclosure are superimposed upon the incident field. The reverberant field may be called a diffuse field if a great many reflected wavetrains cross from all possible directions and the sound energy density is very nearly uniform throughout the field.

Sound Pressure: The total instantaneous pressure at a point in the presence of a sound wave minus the static pressure at that point.

Sound: A disturbance that propagates through an elastic material (air, water) at a speed characteristic of that medium. The physical quantities of most interest are the sound pressure and sound power.

Sound Pressure Level: SPL, in dB, is 20 times the logarithm to the base 10 of the ratio of the pressure of this sound to a reference pressure. (Standard reference is 20 $\mu N/m^2$ for airborne sound. Different reference pressures are sometimes used for underwater sound.)

$$\mathrm{SPL} = 20 \log \frac{P}{0.0002\ \mu\mathrm{bar}} \quad \mathrm{dB\ re\ } 20\ \mu\mathrm{P}$$

Spectrum: The spectrum of a function of time is a description of its resolution into components, each of different frequency and (usually) different amplitude and phase.

Standard Deviation: A numerical indication of the scatter of values of a variable around their mean (symbol σ). Specifically, it is the square root of the mean squared deviation, given by:

$$\sigma = \sqrt{\frac{\Sigma d^2}{n - 1}}$$

where d is the difference between the grand mean and an individual observation and n is the number of observations. In a normal distribution, a range of two standard deviations on each side of the mean will include 95.45 percent of all values, and three standard deviations on each side of the mean, 99.73 percent. When the standard deviation is determined from a sample of values and not from the parent population (which is frequently unknown), the denominator within the square root should be taken in $n - 1$, due to the fact that one degree of freedom out of the total n is used to estimate the mean value x.

T-test: The t distribution can be used in estimation even if $n \geq 30$, provided that the parent population is normally (or approximately normally) distributed.

Waveform: Instantaneous amplitude as a function of time.

Wavelength: The wavelength of a pure tone is the distance between analogous points on two successive waves. Wavelength (λ), frequency (f), and the speed of sound (c) are related by the expression $c = f\lambda$. In most practical situations the sound of interest is more aptly described as noise (random noise) than as a finite composite of pure tones.

Weighting: Prescribed frequency response provided in a sound-level meter.

W.O.T.: Wide open throttle.